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Research Paper

Water and nitrogen budgets under different production systems in Lisbon urban farming

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Public concern is growing over soil and groundwater contamination from the use of agrochemicals in urban farming. Heavily used nitrogen (N) fertilisers are converted to nitrates that can be a health hazard. In this study, water and N budgets over a 1-year period are presented for typical urban vegetable gardens in Lisbon. A conceptual analysis supported by an integrated methodology of field experiments and modelling identified the N surpluses associated with conventional and organic gardens. It is concluded that the gardening systems are continuously cropped using high N and water application rates. For all of the case-study allotments, the N inputs, mainly from organic amendments with diverse N release rates, were higher than the crop uptake generating surpluses that were lost by different processes. On one study site a drainage flux of 280 mm yr^{-1} was calculated, with a mean concentration of 295 mg NO_3^- l^{-1}. On another site N accumulated in the lower soil depths at a rate of 420 kg NO_3^- ha^{-1} yr^{-1}. The cumulative impact of N surpluses on the environment and human health must be considered. To minimise adverse impacts, we propose the selection of organic fertilisers with N release rates close to the crop N uptake, the prevention of excess irrigation to minimise N leaching and gaseous losses and the inclusion of the non-fertiliser N sources in the fertiliser calculations. It is shown how an integrated model can be used to predict the N release dynamics from the organic fertilisers as affected by the moisture conditions.

1. Introduction

As the world turns predominantly urban (UN, 2010) we are facing the challenge of preserving citizen engagement and quality of life within cities (Vásquez-Moreno & Córdova, 2013). Urban agriculture (UAg), usually in small urban garden allotments (UA), may contribute to these aspirations by increasing supply of fresh vegetables, fruits, and other foods, creating an improved microclimate, reusing waste, improving nutrient recycling and water management, and the environmental awareness of city inhabitants (Gómez-Baggethun & Barton, 2013). More information seems to exist on evidence of public health risks posed to urban gardens by urban environment factors than on the risks introduced by UAg into the urban environment. Still, the latter is a source of rising

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Nomenclature

A	constant in the Brooks and Corey water retention equation
C_2	constant in the Brooks and Corey hydraulic conductivity equation
BD	soil bulk density (t m^{-3})
C	carbon
C_{org}	organic carbon
C:N	carbon to nitrogen ratio
C–N	C and N integrated cycles
Conv	conventional fertilisation
D	drainage (mm)
ETa	actual evapotranspiration (mm)
ETo	reference evapotranspiration (mm)
FH	soil fast humus pool (%)
FC	soil water storage at field capacity (mm)
FR	soil fast residue pool (%)
h	soil water pressure head in the Brooks and Corey equations (mm)
h_b	air entry water pressure head in the Brooks and Corey equations (mm)
IH	soil intermediate humus pool (%)
IR	irrigation amount (mm)
K	unsaturated hydraulic conductivity (mm h^{-1})
K_{sat}	saturated hydraulic conductivity (mm h^{-1})
K(h)	hydraulic conductivity curve
LAI	leaf area index
N	nitrogen
N_2	slope of the log(k)–log(h) curve
N_{org}	organic nitrogen
N_{Fert}	N added with the chemical fertiliser (kg ha^{-1})
N_{Gas}	N loss to the atmosphere (kg ha^{-1})
NH_4^+	ammonium ion
NH_4–N	ammonium nitrogen (kg ha^{-1})
N_{Imob}	N immobilised by the soil microorganisms (kg ha^{-1})
N_{Irrig}	N added with the irrigation water (kg ha^{-1})
N_{Lix}	N lost by leaching (kg ha^{-1})
N_{Man}	mineral N released from organic amendments (kg ha^{-1})
N_{Min}	mineral N available from soil organic matter mineralisation (kg ha^{-1})
NO_3^-	nitrate ion
NO_3–N	nitrate nitrogen (kg ha^{-1})
N_{RO}	N lost with the runoff (kg ha^{-1})
N_{Upt}	N used by the crop (kg ha^{-1})
Org	organic fertilisation
P	precipitation (mm)
RMSE	root mean square error
RO	runoff (mm)
SH	soil slow humus pool (%)
SR	soil slow residue pool (%)
SOM	Soil organic matter
UA	urban garden allotments
UAg	urban agriculture
WP	soil water storage at wilting point (mm)
λ	slope of the θ(h) curve
θ_v	volumetric soil water content (m^3 m^{-3})
θ_{FC}	soil water content at field capacity (m^3 m^{-3})
θ_{WP}	soil water content at wilting point (m^3 m^{-3})
θ_s	saturated soil water content (m^3 m^{-3})
θ_r	residual soil water content (m^3 m^{-3})
θ(h)	soil water retention curve
ρ	specific mass (t m^{-3})

governmental concern. A considerable amount of literature exists to advance our understanding of urban ecosystems in their biophysical (Escobedo, Kroeger, & Wagner, 2011; Marsden & Sonnino, 2012; Pataki et al., 2011), economic (Sander, Polasky, & Haight, 2010) and socio-cultural dimensions (Andersson, Barthel, & Ahrné, 2007). The subject was addressed by major initiatives like the Millennium Ecosystem Assessment (McGranahan et al., 2005) and has received increasing attention as part of the policy debate on green infrastructures. However, only a few researchers have attempted to quantify the impact of UAg on the environment, in particular in relation to soil and groundwater contamination. Among them are the works of Huang et al. (2006) and Khai, Ha, and Oborn (2007) who studied the nutrient flows in small-scale urban vegetable farming systems in China; and Kliebsch, Muller, and Van der Ploegh (1998) who reported that in a community in Germany, home gardens with a cover of only 3.5% of the total study area were responsible for 27% of the total amount of nitrogen leached. One of the most serious issues is the N surplus in the UA systems and its rapid movement to surface and ground waters, as the N fertilisers are most heavily used and nitrates are the most mobile ions. Excess N promotes the eutrophication of surface water (Smolders, Lucassen, Bobbink, Roelofs, & Lamers, 2010), along with phosphorus; the degradation of drinking water quality (Bruning-Fann & Kaneene, 1993; Lundberg, Weitzberg, Cole, & Benjamin, 2004), since the nitrate concentrations above 10 mg l^{-1} in drinking water are harmful to health; the increase of greenhouse gas (especially nitrous oxide) emissions (Menz & Seip, 2004); and the alteration of the soil ecosystem (e.g. acidification) (Fenn et al., 1998).

Nitrogen loads in water bodies depend on site specific management, in particular irrigation and fertilisation. It is difficult to maintain the balance of available N required to satisfy crop needs and at the same time to minimise leaching losses. Leaching of the surplus N occurs if an excess of water flows through the bottom boundary of the agro system. The movement of N out of the root zone depends on the soil hydraulic properties, the amount of irrigation and/or precipitation, the amount of N applied, the form of N in the fertiliser, and the time of application. Nutrient balances demonstrate the extent to which any surplus might exist (Osborne, Saunders, Walmsleya, Jones, & Smith, 2010).

Locally available organic materials, especially farmyard manures and bio composts of green and food waste, are a key N nutrient resource in UAg. Nitrates released and leached from these materials as well as from mineral fertilisers, are likely to be a significant source of nitrogen to groundwater

(Katz, Lindner, & Ragone, 1980; Sharma, Herne, Byrne, & Kin, 1996; Wakida & Lerner, 2005). The European Community Nitrates Directive (EEC, 1991) limits the use of agricultural fertilisers and organic amendments in the N Vulnerable Zones aiming to minimise surplus of N and phosphorus (P) losses into the aquatic bodies. These thresholds depend upon the aquifer, the soil and the crops characteristics. As an example, in a Vulnerable Zone in the south of Portugal the organic materials cannot be applied between November and February and the amount to apply cannot provide more than 170 kg mineral N ha^{-1} yr^{-1}.

Farmers should be encouraged to use organic amendments due to their benefits for soil organic carbon, soil aggregate stability and water infiltration (Hati, Mandal, Misra, Ghosh, & Bandyopadhyay, 2006; Mikha & Rice, 2004; Ogle, Breidt, & Paustian, 2005). Knowledge on short and long-term availability of mineral N from organic materials through mineralisation is important to optimise the benefits (Gutser, Ebertseder, Weber, Schraml, & Scmidhalter, 2005). The C:N ratio of materials with different origins is an important factor affecting this process (Abbasi, Hina, Khalique, & Khan, 2007; Overcash, Humenik, & Miner, 1983; Qian & Schoenau, 2002); however, the mineralisation process depends also on abiotic factors (e.g. soil water and temperature), thus laboratory determination of the C:N ratio is not *per se* enough to understand its dynamics. Simulation models of the soil–plant–atmosphere continuum, coupling the conceptual descriptions of water, heat and C–N dynamics provide a unique means of addressing these issues (Diekkruger, Sondgerath, Kersebaum, & McVoy, 1995; Gabrielle, Da-Silveira, Houot, & Michelin, 2005). Through model scenario analysis a range of potential options (BMPs) involving organic materials, amounts applied, and irrigation, can be evaluated, and the most promising ones can be field tested (Cameira, Fernando, Ahuja, & Ma, 2007) with the scope of issuing recommendations for irrigation and fertilisation management in gardens.

2. Case study context and objectives

In Lisbon a 2010 survey identified around 77 ha of cultivated garden allotments under the municipal regulations. These regulations refer almost exclusively to the spatial organisation and very little to the agricultural practices. The allotments range in average area from 150 to 200 m^2 and involve a cost of 1.5 € m^{-2} to the user, who has available water for irrigation either piped or stored. Today a value around 100 ha is estimated for the regulated allotments. However, this number does not take into account the "informal" urban gardens created by individuals or associations occupying vacant lots, underutilised parks, and other public open spaces (Cabannes & Raposo, 2013). There is still no official count of this area, although it is known that it has increased exponentially during the last five years. In both types of allotments soil fertility is maintained by the application of large amounts of organic materials with different origins. No guidelines on amounts and application times for either the fertilisers or irrigation are provided to the farmers. It is important to assess the environmental impacts upon the soil and the groundwater, of the current management practices in the UA.

The objectives of this study were to: a) document the actual management practices related to irrigation and fertiliser (organic and mineral) application in four selected case-study urban garden allotments (UA) in Lisbon; b) evaluate the water and N balances for the selected UA and to identify N surpluses associated with both the conventional and organic type of production; and c) propose alternative management practices in order to minimise nitrogen losses applicable to the UA cases and broadly. The applied methodology integrated field experiments and modelling. Experiments included enquiries to the urban farmers, *in situ* characterisation of soil and crop sequences and soil water monitoring. The cropping system Root Zone Water Quality Model (RZWQM) was used to simulate the water and C–N dynamics in the urban production systems amended with different types of manures, bio composts (green and food waste) and mineral fertilisers.

3. Materials and methods

3.1. *Site description and selection of the case-study allotments*

The study was carried out in Lisbon, the capital city of Portugal, with an official population of three million in the metropolitan area (Census, 2011). In general terms, the city of Lisbon has a Mediterranean-type climate characterised by hot and dry summers and concentrating most of the rainfall between October and April. The mean annual temperature is around 16 °C, and the mean annual precipitation is 700 mm (CML, 2010). Beneath the city of Lisbon lays an undifferentiated water body, designated as "OO1RH5- Orla Ocidental Indiferenciada da Bacia do Tejo", presenting an area of 1371.2 km^2 with an average recharge of 87.64 m^3 yr^{-1} (Lobo Ferreira et al., 2011). This water body underlays several subwatersheds, one of which being the Lisbon watershed (17,196 ha). According to the most recent report of the Agriculture and Environment Ministry (ARH Tejo, 2011) there are signs of groundwater contamination by nitrates and phosphorus in this sub-basin. Experts associate this problem with both point-source origins (industry) and diffuse origins such as from agriculture and forestry. There might also be nonagricultural diffuse sources, such as leakage from disposal networks, animal waste sites, and atmospheric deposition. The contribution of each source has not been quantified yet. This cited report rates the overall quality of this underground water body as "below good".

During November 2011, an enquiry was conducted from a random group of 23 allotments in the municipality area, including both municipal regulated and non-regulated cases (Fig. 1). The enquiry contained three parts: (i) introduction of the study objectives; (ii) questions regarding socio-economic issues (goals, area cultivated, and choice of crops); (iii) questions regarding the management practices with emphasis on organic and mineral fertiliser applications, vegetable planting, and irrigation. After data analysis, a group of farmers was selected based upon their willingness to cooperate in the study, providing relevant information. From this group four study case allotments were selected based upon the objectives: (i) to include two types of farmer–municipality

Fig. 1 – Municipality of Lisbon and its boroughs (●enquires; ●case study allotments).

relations; (ii) to include in each study site allotments with different fertilisation management histories. In the organic (Org) plots only organic fertilisers are applied, consisting in bio composts and animal manures. In the conventional (Conv) plots, mineral fertilisers are applied although complemented by organic amendments; and (iii) to include soils with different water movement and solute transport properties. The four selected case-study allotments shown in Table 1 represent the average characteristics of 23 allotments, having an average size of 163 m^2, being small-scale family-oriented and using high inputs of organic fertilisers all year around. Data were collected in these allotments from January 2012 to March 2013.

3.2. *Meteorological data*

To calculate the crop water requirements (ETa), reference evapotranspiration (ETo) was computed with the FAO-PM method (Allen, Pereira, Raes, & Smith, 1998) using daily meteorological data collected at the Tapada da Ajuda weather station in Lisbon (38° 42′ N; 9° 11′ W; altitude: 60 m) for the period from January 2012 to March 2013.

3.3. *Soil properties and soil water measurements*

In the Ajuda urban gardens the soil was natural while in Granja gardens it had been transported there to create a 1 m layer suitable for vegetable production. Undisturbed soil samples were collected from the top layer (0.0–0.3 m) to characterise soil bulk density (BD) and water contents at field capacity (θ_{FC} – the maximum water content that a particular soil can present 48 h after saturation) and wilting point (θ_{WP} –

Table 1 – Case study urban allotments (UA).

UA	Relation with the municipality	Soil type	Fertilisation history
GOrg	Regulated	Sandy clay loam	Organic
GConv	Regulated	Sandy loam	Mineral complemented by organic
AOrg	Non-regulated	Clay loam	Organic
AConv	Non-regulated	Clay loam	Mineral complemented by organic

soil water content at which the plant starts to wilt). Disturbed soil samples were collected at the same depth for particle size distribution and chemical analyses. Mineral N was determined by molecular absorption spectroscopy (Maynard & Kalra, 1993). Soil carbon (C) was determined by wet oxidation (Tiessen & Moir, 1991) and the soil organic matter (SOM) was calculated as C divided by 0.58 (Maynard & Kalra, 1993). Soil water contents, θ_v, were measured twice a month for the top layer using the gravimetric method. For this purpose, three soil samples were collected at random locations inside the allotments on each date.

3.4. Crop systems

In all cases, the vegetables grown were for domestic consumption. The most frequent cropping system was a sequence of two or more crops a year. There was a considerable diversity in the type of vegetables grown at both sites and it was not possible to make a thorough survey of all of them. The most frequent crops were *Cucurbita moschata* (pumpkin), *Cucurbita pepo* L. (zucchini), *Lactuca sativa* (lettuce), *Solanum tuberosum* (potato), *Solanum melongena* L. (egg plant), *Brassica oleracea* (cabbage), *Spinacia oleracea* (spinach), *Vicia faba* (fava beans) *and Lycopersicon esculentum* (tomato). Planting dates, durations and planting densities were obtained from the enquiry.

3.5. Management practices

The crops were irrigated year round especially in spring and summer due to the high climatic demand and the absence of precipitation. In the autumn and winter, irrigation supplemented the precipitation inputs. Irrigation water was often applied using a hose connected to the public supply network or pumped from a well. Irrigation flow rates were measured *in situ* using the volumetric method and irrigation times were recorded for some events. From *in situ* observation it was clear that the farmers were over irrigating their crops. Details about the types of manure/fertiliser materials, amounts and methods of application were recorded. Four types of organic materials were used, all applied in early spring at the time of planting for the first crop in the sequence. As to the mineral fertilisation a total amount of 150 kg N ha^{-1} (16% $N-NO_3$ and 84% $N-NH_4$) was applied in GConv (Granja conventional) and 102 kg N ha^{-1} (50% $N-NO_3$ and 50% $N-NH_4$) was applied in AConv (Ajuda conventional). The mineral N fertilisers were applied as top dressing 20 days after planting of each crop in the sequence and incorporated in the soil. All the gardeners decided for themselves the application times and amounts both for fertilisation and irrigation. Samples from the different irrigation water sources (wells and public delivery net) were collected and later analysed for $N-NO_3$ using the selective ion electrode method.

3.6. Water and N system modelling

3.6.1. Root Zone Water Quality Model overview

RZWQM was developed by the Agricultural Systems Research Unit at Fort Collins (Ahuja, Rojas, Hanson, Shaffer, & Ma, 2000). It integrates state-of-the-science knowledge of agricultural systems into a tool for assessing the environmental impact of alternative management strategies and predicting management effects on crop production. RZWQM has been successfully applied and its components have undergone extensive evaluation. These components are soil hydraulics and water movement (Cameira, Fernando, Ahuja, & Pereira, 2005; Cameira, Sousa, Farahani, Ahuja, & Pereira, 1998), evapotranspiration (Alves & Cameira, 2002), organic matter/nitrogen cycling (Long & Sun, 2012; Ma et al., 1998; Wang, Zhang, Zhang, & Bai, 2012), plant growth (Ahuja et al., 2000) and management practices (Saseendran et al., 2007). The components of interest for this study are:

3.6.1.1. Soil water dynamics. The soil hydraulic properties, soil water retention curve $\theta(h)$ and unsaturated hydraulic conductivity curve k(h), are described by the Brooks and Corey functions with slight modifications (Ahuja et al., 2000). The soil water retention curve $\theta(h)$ is expressed as

$$\begin{aligned} \theta_v &= \theta_s - A|0.1h| && \text{when} |h| < |h_b| \\ \theta(h) &= \theta_r + B|0.1h|^{-\lambda} && \text{when} |h| \geq |h_b| \end{aligned} \tag{1}$$

where θ_v is the volumetric soil water content ($m^3\ m^{-3}$), h is the soil water pressure head (mm), θ_s and θ_r are saturated and residual soil water contents ($m^3\ m^{-3}$), A is a constant, usually set to zero, h_b is the air entry water pressure head (mm) and λ is the slope of the log(θ)–log(h) curve. The corresponding unsaturated hydraulic conductivity versus pressure head relationship, K(h), is expressed as

$$\begin{aligned} K(h) &= K_{sat} && \text{when} |h| < |h_b| \\ K(h) &= 10C_2|0.1h|^{-N_2} && \text{when} |h| \geq |h_b| \end{aligned} \tag{2}$$

where K_{sat} is the saturated hydraulic conductivity (h = 0) (mm h^{-1}), h_b is the air entry water pressure head (mm) and N_2 is the slope of the log(K)–log(h) curve.

The Green-Ampt equation is used to calculate infiltration rates in the soil. Between successive rainfall or irrigation events, the soil water is redistributed by a finite-difference numerical solution of the Richards' equation where the root water uptake is given by the Nimah and Hanks model (Nimah & Hanks, 1973).

3.6.1.2. Evapotranspiration. The calculation is based on the Shuttleworth and Wallace dual surface version of the Penman–Monteith equation (Ahuja et al., 2000).

3.6.1.3. Nitrogen transformations. The C–N module simulates the major pathways of the soil C and N dynamics including mineralisation–immobilisation of crop residues, manure, other organic wastes, and of the soil humus fraction, denitrification, ammonia volatilisation and nitrification. The C–N cycling is affected by management practices such as irrigation, manure application and mineral fertilisation. SOM is distributed over five computational pools and decomposed by three microbial mass populations. Mineral nitrogen pools are maintained for ammonium nitrogen (NH_4–N) and nitrate nitrogen (NO_3–N). For all the pools, the basic form of the decay rate equations for organic matter differs only by the values of the user-supplied rate coefficients. The equations are all first order with respect to the carbon substrate source (Shaffer, Ma, & Hansen, 2001).

Nitrogen is released as inorganic NH_4^+, during the decay process and may be nitrified to NO_3^- by autotrophic bacteria, following a zero order equation. Nitrate from nitrification and applied fertilisers is subject to denitrification under anaerobic conditions using a first-order equation. Ammonia volatilisation is modelled based on partial pressure gradient of NH_3 in the soil and air.

A detailed description of the processes, equations and calculations is given by Ma et al. (2000) and Shaffer et al. (2001). Organic wastes are treated as residues and partitioned into slow and fast residue pools (Ma et al., 1998), whereas the amount of ammonium in the manure is added into the NH_4^+ pool directly. This component is complex, and the required inputs are determined through an initialisation wizard and calibration.

3.6.1.4. *Nitrogen uptake*. The amount of N that passively enters the plant is associated with the plant transpiration. If passive N uptake is unable to satisfy plant N demand, the active uptake occurs in a manner similar to the Michaelis–Menten substrate model (Ahuja et al., 2000).

3.6.1.5. *Nitrate transport and leaching*. During water redistribution between rainfall or irrigation events, nitrates in solution move with the Darcy water flux from one depth to another, including upward movement due to evaporation. Nitrate-N leached from the crop root zone, is computed by combining an estimate of nitrate-N dissolved in the soil pore water with estimates of soil water flux.

3.6.2. *Root Zone Water Quality Model parameterisation*

RZWQM was used to simulate the processes related to fertilisers and irrigation in order to quantify water and N budgets for the four case-study vegetable growing systems. The bottom boundary of the simulation domain corresponded to the soil depth of 1 m, with a free drainage condition. The upper boundary corresponded to the top of the canopy. Daily simulations were performed for a period of one year (March 2012–March 2013), corresponding to a complete crop sequence.

Model parameterisation was based on measured data or reference values from the literature. It included (a) for the soil water dynamics: bulk density, θ_v at 10 and 1500 kPa and K_{sat} by layers; (b) for the crop development: maximum LAI, height and rooting depth and potential N uptake; (c) for the actual evapotranspiration: crop and soil parameters described in (a) and (b); and (d) for the C–N dynamics: SOM, organic pools partitioning, interpool transfer coefficients, applied organic material properties.

The Brooks & Corey functions that describe the soil hydraulic properties, fundamental for the description of the soil water dynamics, were inferred by applying the methods described in Ahuja et al. (2000) to the measured soil properties of texture and bulk density. The soil organic C–N module was parameterised by adjusting the coefficients determining the interpool transformations (section 3.6.1) with respect to literature reference values. To achieve this, the model was run with the measured SOM contents for a long-term (20-years) simulation with no N additions. The transfer coefficients were adjusted so as to provide mineralisation according to the rule that for each 1% of SOM the soil annual mineralisation should be on average 20 kg ha^{-1} for the arable soil layer (top 0.3 m) (Scheppers & Mosier, 1991).

The most frequent crop sequences found for each site were used for the modelling process. The crop parameters were obtained from field observations or from the enquiries, except for the leaf area index which was based upon the literature (Allen et al., 1998). The final organic C and ammonium contents and the C:N of the amendments were calculated according with the relative proportion of each material in the mixture. Table 2 shows the base properties of the different materials used for the calculations (Abbasi et al., 2007; Geisseler et al., 2012).

After parameterisation, the model was applied without any further parameter calibration and the predictions were validated against measured values of soil water and expected SOM mineralisation rates. The goodness of fit was quantified by the RMSE normalised by the average of the measured values (Ma et al., 2011).

4. Results

4.1. *System characterisation and model parameterisation*

The soil physical properties and the saturated hydraulic conductivity (K_{sat}), which was estimated based upon soil texture and BD, are presented in Table 3. The Brooks & Corey functions describing θ(h) (Eq. (1)) and K(h) (Eq. (2)) are shown in Fig. 2. The results indicate that soils from Granja and Ajuda present two distinct hydraulic behaviours essentially due to the different particle size distribution. The Ajuda soils show higher values for saturated moisture content (θs), θ_{FC} and θ_{WP} than the Granja soils (Fig. 2a), reflecting a high storage capacity for water (238 mm m^{-1}). The slope of the retention curve (λ) for the Granja soils is steep meaning that it will drain quickly for relatively low negative pressures (low suctions). The water storage capacity per metre is 90 mm and 120 mm for GOrg and GConv respectively. The Ajuda soil had lower K_{sat} (2.3 mm h^{-1}) but larger unsaturated conductivity, meaning that it will conduct water slowly and for longer periods (Fig. 2b). The GConv and GOrg soils had K_{sat} of 120 mm h^{-1} and 20 mm h^{-1} respectively.

Table 4 presents N related results for soil and water. The measured soil mineral N contents were used as initial

Table 2 – Organic amendments components and their basic properties.

Type	ρ	Water	C_{org}	N_{org}	C:N
	($t\ m^{-3}$)	(% of volume)	(% of dry mass)		
Horse manure	0.95	72	43	1.6	26.8
Chicken manure	0.50	53	52	5.4	9.6
Goat manure	1.00	69	39	2.7	14.4
Green waste	0.95	87	35	3.2	10.9
Food waste	1.00	69	37	2.5	14.8

ρ is the specific mass; C_{org} is the organic carbon; N_{org} is the organic nitrogen; C:N is the carbon to nitrogen ratio.

Table 3 – Soil physical properties for the cultivated layer.

UA	Particle size ($g\ kg^{-1}$)			BD ($t\ m^{-3}$)	($m^3\ m^{-3}$)		K_{sat} ($mm\ h^{-1}$)
					θ_{FC}	θ_{WP}	
	Sand	Silt	Clay		10 kPa	1500 kPa	
GOrg	575	173	252	1.59	0.24	0.15	20
GConv	755	121	124	1.59	0.18	0.06	120
AOrg	440	233	328	1.20	0.37	0.13	2.3
AConv	440	233	328	1.20	0.37	0.13	2.3

BD is the bulk density; θ_{FC} is the soil water content at field capacity; θ_{WP} is the soil water content at wilting point; K_{sat} is the saturated hydraulic conductivity.

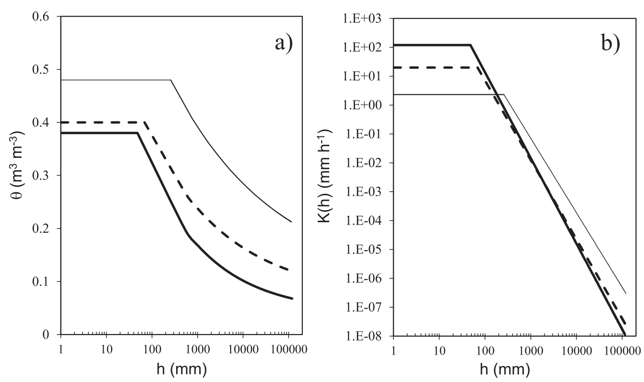

Fig. 2 – Brooks & Corey functions describing the soils hydraulic properties: a) soil water retention curve; b) hydraulic conductivity curve.

conditions for the modelling of the N budget. The higher values for Ajuda soils in comparison to Granja soils, can be associated with the higher SOM and the application of large quantities of organic materials with a low C:N. Based upon the SOM contents, the interpool transfer coefficients were adjusted as described under Materials and Methods. The nitrates content in the water exceeded or equalled the maximum allowable for drinking water (50 mg NO_3^- l^{-1}) (EEC., 1991) in all of the allotments excepting GOrg where the irrigation water came from the public drinking water supply. This may indicate that the water and N budgets have been unbalanced for a significant period of time. Silva et al. (2007) measured values between 2.3 and 134.4 mg NO_3^- l^{-1} in 13 wells located in a further north location.

Table 5 shows the most representative crop sequences according to the enquiries and the crop parameters used in the modelling process. Figure 3 presents the average irrigation depths per week calculated from field observations, and the weekly ETo calculated from the meteorological data. The weekly amounts and the irrigation frequency (from the enquiries) were used to define the irrigation scheme for each scenario. Table 6 shows the soil related parameters for the C–N dynamics resulting from the long-term (20 years) simulation. Table 7 shows the amounts and chemical composition of the organic mixtures applied in each allotment, as they were input to the model. Except for GConv, the C:N of the mixtures had low values as a result of the high proportion of chicken manure.

Table 4 – N related measurements.

UA	N mineral ($mg\ kg^{-1}$)	SOM ($g\ kg^{-1}$)	NO_3^- in the irrigation water ($mg\ l^{-1}$)
GOrg	4.8	0.9	<5 (public supply)
GConv	6.6	2.4	83.5 (well #1) and 66.8 (well #2)
AOrg	97.7	6.2	46.8 (well)
AConv	11.2	3.0	46.8 (well)

UA is the urban garden allotment; SOM is soil organic matter.

4.2. *Soil water and soil N balances for the urban allotments*

4.2.1. *Granja organic culture system*

Figure 4b shows the predicted and the observed soil water storage (SWS). The RMSE of the predictions was 5.7% of the average observed SWS, assuring some reliability in the prediction of drainage. The highest deviations occurred during the irrigations seasons (Fig. 4a) and were associated with the uncertainty in the quantification of the water input. At the beginning of the simulation period the SWS was already at field capacity (Fig. 4b) due to previous precipitation events, that is why any water input was lost by drainage (Fig. 4c). Three drainage peaks occurred, one during the zucchini cycle associated with the precipitation events, the other during the tomato cycle due to excessive irrigation and finally one during the lettuce cycle associated with the precipitation events. Table 8 shows the computation of soil water balance for the 1-year cycle. An amount of 261 mm was lost by drainage, representing 23% of the inputs and 30% of the ETa. One third of this loss occurred during the tomato cycle.

The NO_3–N stored in the top layer increased rapidly after the organic amendment due to the rapid mineralisation of the organic material (Fig. 5b). When rainfall occurred, a considerable part of NO_3–N was transported to the underlying soil, originating a leaching peak (Fig. 5c). The zucchini plants, which extended its roots up to 300 mm, suffered N uptake deficiency (Fig. 5a). Up to day 250 (tomato cycle) the NO_3–N that became available by mineralisation in the top layer was being transported to the lower layers originating a continuous and uniform leaching flux at the depth of 1 m. From day 250 and during a considerable part of the lettuce cycle, there were no water fluxes to transport the NO_3–N. In addition, N was

Table 5 – Crop parameters for the most representative crop sequences.

Crop sequence	LAI	Crop height (mm)	Rooting depth (mm)	Cycle (days)	Planting density (ha^{-1})	Planting date
Granja Org (GO)						
Zucchini	4	300	300	74	12,000	01-Abr-12
Tomato	4	1000	950	107	12,000	15-Jun-12
Lettuce	2	300	300	60	150,000	01-Out-12
Cabbage	5	400	400	120	20,000	01-Dez-12
Granja Conv (GC)						
Tomato	4	1000	950	90	12,000	01-Abr-12
Pumpkin	7	500	400	120	10,000	01-Jul-12
Fava bean	4	600	600	150	25,000	01-Nov-12
Ajuda Org (AO)						
Cabbage	5	350	350	83	20,000	13-Fev-12
Pumpkin	7	500	400	110	10,000	21-Mai-12
Lettuce	2	300	300	70	150,000	12-Set-12
Lettuce	2	300	300	70	150,000	22-Nov-12
Ajuda Conv (AC)						
Potato	4	600	500	90	40,000	15-Mar-12
Egg plant	3	800	800	110	12,000	15-Jun-12
Lettuce	2	300	300	75	150,000	05-Out-12
Spinach	4	300	300	71	600,000	20-Dez-12

LAI is the leaf area index.

mineralised at a rate higher than crop uptake which led to an increase of the soil N storage until precipitation transported the surplus to the bottom layer and finally out of the root zone. Consequently, the subsequent crop of cabbage suffered N uptake deficiency (Fig. 5a). The N budget (Table 9) shows that 35% of the mineral N released from the organic amendments was lost. During the cultural year the nitrate storage in the soil increased by 103 kg ha^{-1}.

4.2.2. *Granja conventional culture system*

The model predicted SWS with a normalised RMSE of 4.7% (Fig. 6b). The drainage peak originated with the first spring rainfall was lower than in Granja Organic, since the vegetable crop installed at the time had a more extensive rooting system. With the second precipitation event (in fall) there was a quick drainage response since the soil had low water retention capacity and the fava bean roots were in the early development stage (Fig. 6c). A total amount of 300 mm was lost by drainage below the maximum root zone (Table 8), representing 26% of total inputs and 33% of the ETa. No significant drainage losses occurred during the tomato and pumpkin cycles (15 and 10%). The largest loss percentage occurred in the cycle of fava bean (55%) in association with the irrigation. The crop used only 49% of the inputs, which were clearly higher than the crop needs (ETp).

The N inputs in this system included the N released from organic amendments and from the chemical fertiliser (Fig. 7b), N released from the endogenous SOM and the N in the irrigation water (83.5 mg NO_3^- l^{-1}). The NH_4^+ present in the fertiliser was rapidly nitrified. No leaching occurred during the tomato cycle due to its deep roots and high uptake potential (Fig. 7a). However, due to the slow N release from the organic amendment (mainly horse manure with high C:N) the tomato plants suffered some deficit of N. The pumpkin used the available N at the potential rate, but due to the shallow root system the surplus N was gradually transported to lower layers. Later, during the fava bean cycle, the accumulated N was leached below the root zone by the water fluxes associated with precipitation events. Table 9 shows that 35% of N provided by manure, chemical fertiliser and irrigation water was lost by leaching, gaseous losses and/or immobilisation. The most significant losses occurred during the fava bean cycle, being insignificant for the other two crops. The nitrate storage in the soil increased by 91 kg ha^{-1} during the cultural year.

4.2.3. *Ajuda organic culture system*

SWS was predicted with a normalised RMSE of 5.3%. Since the beginning of the irrigation season, SWS in the soil profile was always above the FC (Fig. 8b), resulting in a continuous

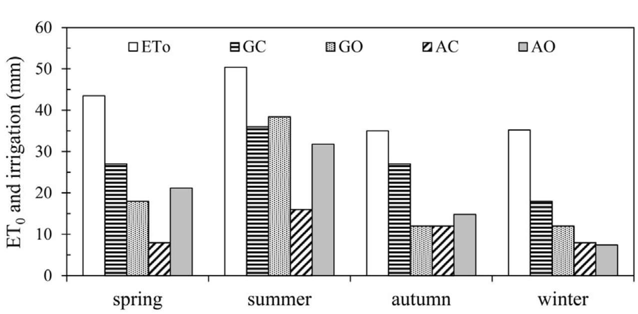

Fig. 3 – Weekly ETo and irrigation amounts.

Table 6 – Soil related parameters for the C–N dynamics.

UA	Pools (% SOM)			Interpool coefficients			
	FH	IH	SH	SR-IH	FR-FH	FH-IH	IH-SH
GOrg	16	4	80	0.3	0.3	0.3	0.3
GConv	6	14	80	0.3	0.3	0.3	0.3
AOrg	16	4	80	0.1	0.1	0.6	0.4
AConv	6	14	80	0.1	0.1	0.3	0.3

FH – fast humus; IH – intermediate humus; SH – slow humus; SR – slow residue; FR – fast residue.

Table 7 – Organic mixtures applied and their chemical properties.

UA	Source	Application rate ($t\ ha^{-1}$)	Organic C ($t\ ha^{-1}$)	NH_4–N ($kg\ ha^{-1}$)	C:N
GOrg	Bio compost (green and food waste) + manure (25% horse, 50% chicken, 25% goat)	7.8	3.1	198	14.3
GConv	Bio compost (green and food waste) + horse manure	4.5	1.8	90	20.0
AOrg	Manure (15% horse, 50% chicken, 30% goat)	11.1	4.5	119	13.2
AConv	Manure (15% horse, 50% chicken, 30% goat) + green waste	5.1	2.1	136	13.0

UA is the urban allotment.

drainage flux associated with high inputs (Fig. 8c). Table 8 shows that drainage (D) and runoff (RO) corresponded to 12 and 4% respectively of the total inputs. SWS increased 17% during the 1-year cycle, indicating accumulation of water in the profile. The most significant losses occur in the pumpkin and second lettuce cycles. In the first case, where the inputs were clearly higher than crop needs, the losses were associated with excessive irrigation.

This allotment showed the largest amount of manure applied (60 $t\ ha^{-1}$ with a C:N of 13.2), because the farmer produced poultry and needed to get rid of the waste. In addition, the NO_3^- concentration in irrigation water was high (46.8 $mg\ l^{-1}$), imposing a heavy N load on the system. Due to the low C:N, mineral N was provided at a rate much higher than the crop uptake rate. NO_3–N accumulated in the profile and the storage reached 500 $kg\ ha^{-1}$. Later, with the autumn/winter rains, nitrate was transported to the lower soil layers (Fig. 9b), constituting a leaching potential. The N budget for the 1-year cycle (Table 9) shows that 40% of the N inputs (organic amendment + N in irrigation water) were lost significantly in the 2nd cycle of lettuce. Mineralisation of the SOM was also an important input, especially during the cabbage and pumpkin cycles (spring and summer). During the cultural year, the nitrate storage in the soil increased by 480 $kg\ ha^{-1}$ indicating an important accumulation of the nutrient.

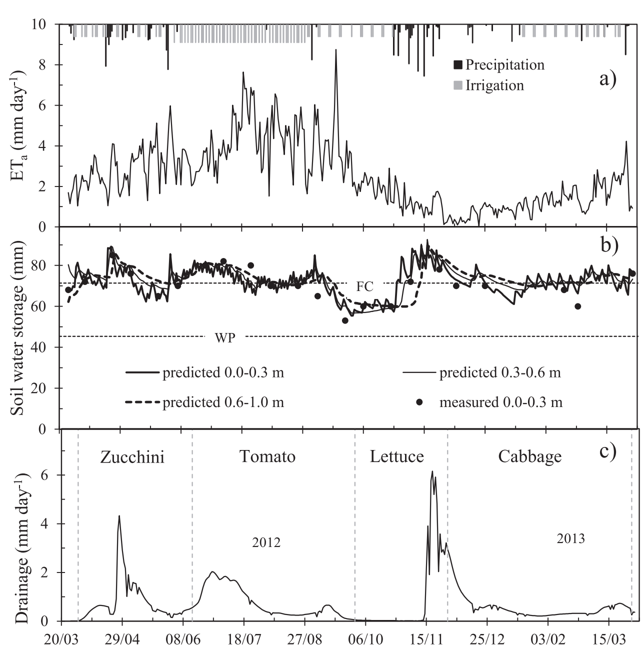

Fig. 4 – Water balance components for the Granja Org system (FC – field capacity, WP – wilting point).

4.2.4. *Ajuda conventional culture system*

SWS was predicted with a RMSE of 6.2%. Figure 10a shows that although the water storage in topsoil was always high, the profile FC was only exceeded during the autumn rainfall, in the lettuce cycle. Table 8 shows that no drainage occurred at the bottom of the profile as a result of the low soil permeability and high water storage capacity. Some runoff (RO) occurred, particularly during the lettuce cycle since the precipitation rate was higher than the soil infiltration rate.

Figure 11a shows the NO_3–N storage in the soil and the N inputs corresponding to the organic amendment, SOM mineralisation, mineral fertilisation and irrigation water contribution (46.8 $mg\ l^{-1}$ NO_3–N). For most of the simulation period, N–NO_3 was stored in the upper soil layer. When SWS reached FC the drainage flow transported the nitrate to the underlying soil away from the roots. At this time lettuce showed a severe N deficit (Fig. 11a). The limited water movement through the profile resulted in the absence of leaching (Table 9). However, the N storage in the soil was always very high. The autumn–winter cycle was characterised by a prolonged period with soil water above FC which, together with high levels of NO_3–N in the profile. Table 9 shows 41% of the N supplied was lost, mainly to the atmosphere. Most of the losses occurred during egg plant and spinach cycles in spring–summer and autumn–winter respectively. Over the 1-year cycle the N storage in the soil profile increased by 170%, accumulating in the bottom of the root zone.

5. Discussion

5.1. *Nitrogen surpluses*

The N inputs were higher than the outputs by crop uptake for all of the case-study allotments, generating N surpluses that were lost by different processes according to system characteristics. Several factors contributed to the N surplus as discussed next.

5.1.1. *Non fertiliser sources of N*

Two important non fertiliser sources of N were detected: the endogenous SOM and the N present in the irrigation water sources. Ajuda Organic site had, according to Alves (1986), a

Table 8 – Predicted water budget (in mm) for the top 1 m of soil.

Crop	Period (Days)	Storage Initial	Storage Final	P	IR	D	RO	ETa
Granja Org								
Zucchini	74	153	151	124	144	60	0	221
Tomato	107	155	112	22	444	80	0	449
Lettuce	60	115	160	156	48	58	0	91
Cabbage	120	158	139	64	126	63	0	148
Total	361	153	139	365	762	261	0	909
Granja Conv								
Tomato	120	162	156	124	198	48	0	324
Pumpkin	150	160	157	37	450	49	0	415
Fava beans	90	163	174	187	180	203	0	180
Total	360	162	174	347	828	300	0	919
Ajuda Org								
Cabbage	83	182	270	160	112	1	8	159
Pumpkin	110	252	230	63	406	50	10	425
Lettuce	70	228	281	132	70	12	26	191
Lettuce	70	277	213	58	7	62	2	74
Total	333	182	213	413	595	125	45	849
Ajuda Conv								
Potato	90	119	158	145	124	0	1	248
Egg plant	110	160	142	22	340	0	0	397
Lettuce	75	143	234	164	48	0	10	97
Spinach	71	241	201	25	44	2	0	78
Total	346	119	201	356	556	2	11	820

P is the precipitation, IR is the irrigation, D is the drainage, RO is the runoff, ETa is the actual evapotranspiration.

high SOM content (6.2 g kg^{-1}) while the remaining sites had lower average SOM contents (3.0, 2.4 and 0.9 g kg^{-1} respectively). Howorth (2011) presented similar values for other Lisbon urban allotments. Table 10 shows the estimated contribution of the referred non fertiliser sources and its importance as a percentage of crop N uptake, which should be considered when calculating the fertilisation needs.

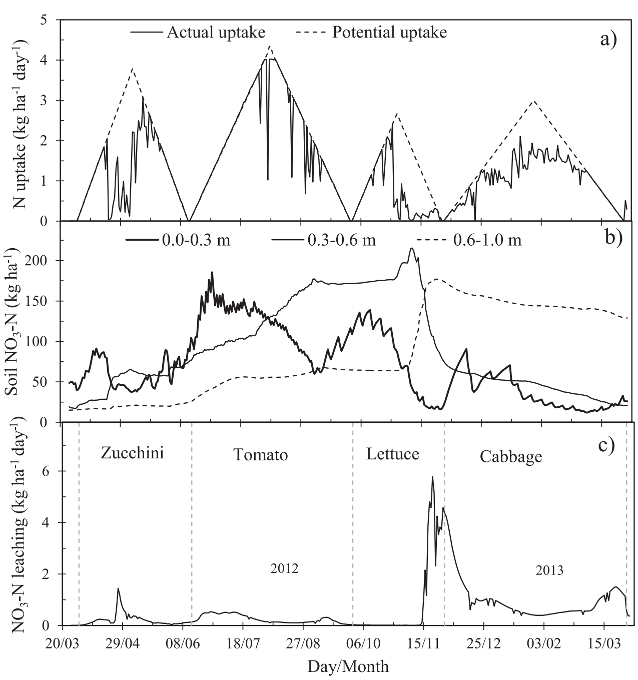

Fig. 5 – Predicted nitrogen balance components for the Granja Org system (⟶organic fertilisation; - - -›mineral fertilisation).

5.1.2. *The C:N of the organic amendments*

Since the N transport in the soil is closely linked with the water movement, leaching fluxes follow a pattern similar to the drainage fluxes. However, NO_3–N leaching in GConv was less than in GOrg despite the similarity in the drainage fluxes. The reason is that in GOrg the mixture had a low C:N (14.3) due to the high amount of chicken and sheep manure in its composition. N was mineralised at a rate higher than crop uptake rate, causing NO_3–N accumulation in the profile with considerable potential for leaching (Fig. 5b,c). In the case of GConv, the higher C:N (20) associated with a higher percentage of horse manure in the mixture, produced a more gradual release of mineral N. As a result, crop uptake was more efficient, decreasing the N surplus in the profile as well as the leaching potential (Fig. 7b,c). The modelling approach made it possible to single out the mineralisation of endogenous and exogenous SOM and therefore, estimate the N release rate from the organic amendments, which are presented in Table 10. Similar results were provided by Bitzer and Sims (1998) and Eghball, Wienhold, Gilley, and Eigenberg (2002). The mixture of the organic materials must aim for a C:N within the desired range of 20–30, depending upon the site particular soil water conditions (Li & Evanylo, 2013) to match the N release rate with the N uptake rate and minimise the surplus.

5.2. *Pathways of N losses and environmental impacts*

The pathways of N losses detected in this study were leaching, volatilisation, denitrification and transport with the runoff,

Table 9 – Predicted mineral N budget for the top 1 m (in kg ha^{-1}).

Crop	Period	N storage		N_{Min}	N_{Man}	N_{Fert}	N_{Irrig}	N_{Lix}	N_{RO}	N_{Upt}	N_{Gas}	N_{Imob}
	(Days)	Begin	End									
Granja Org: 40 t organic amendment ha^{-1} (C:N = 14.3)												
Zucchini	74	73	248	0	274	0	0	16	0	89	30	40
Tomato	107	250	356	6	396	0	0	27	0	218	13	0
Lettuce	60	349	274	2	75	0	0	56	0	39	7	0
Cabbage	120	275	176	8	117	0	0	113	0	125	7	0
Total	361	73	176	17	863	0	0	212	0	470	56	40
Granja Conv: 20 t organic amendment ha^{-1} (C:N = 20)												
Tomato	90	62	91	12	84	125	41	0	0	133	36	46
Pumpkin	120	92	210	20	63	125	67	36	0	198	1	2
Fava bean	150	210	153	16	52	125	36	120	0	80	20	1
Total	360	62	153	48	197	375	144	156	0	411	56	48
Ajuda_Org: 60 t organic amendment ha^{-1} (C:N = 13.2)												
Cabbage	83	34	242	50	525	0	14.1	0	5	143	137	43
Pumpkin	110	242	395	48	495	0	43	3	0	230	240	0
Lettuce	70	395	450	15	156	0	9	1	25	68	56	0
Lettuce	70	450	518	10	102	0	1	18	0	34	26	0
Total	333	34	518	123	1278	0	67	22	30	474	459	43
Ajuda_Conv: 30 t organic amendment ha^{-1} (C:N = 13)												
Potato	74	119	220	18	230	103	14	0	4	127	117	53
Egg plant	107	242	378	33	310	103	36	0	0	249	204	0
Lettuce	60	383	487	6	53	103	7	0	15	20	42	0
Spinach	120	483	606	6	57	103	8	2	0	52	27	0
Total	361	119	324	63	650	412	66	2	19	448	390	53

N_{Min} is the N from SOM mineralisation; N_{Man} is the N available from organic amendments; N_{Fert} is the N added with chemical fertilisers; N_{Irrig} is the N added with the irrigation water; N_{Lix} is the N lost by leaching; N_{RO} is the N lost with the runoff, N_{Upt} is the N used by the crop, N_{Gas} is the N loss to the atmosphere, N_{Imob} is the N immobilised by soil microorganisms.

with adverse impacts for different parts of the environment, surface water, groundwater, or air quality. Immobilisation by the soil microbes can also be considered a N loss, although it is temporary. Figure 12 shows the relative importance of the different pathways. In Granja the main loss process was the convective transport with the drainage water (leaching). The water balance calculations indicate that 261 and 300 l m^{-2} yr^{-1} were drained out of the root zone in GOrg and GConv, respectively. These water fluxes presented an average

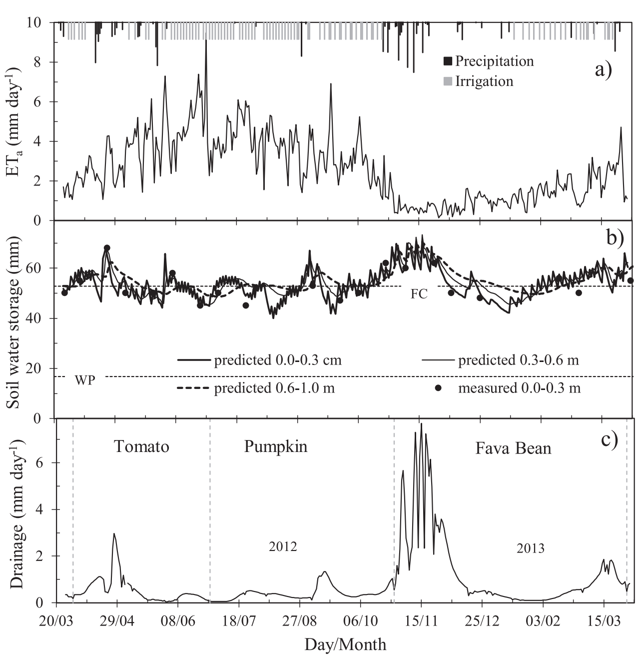

Fig. 6 – Water balance components for the Granja Conv system (FC – field capacity, WP – wilting point).

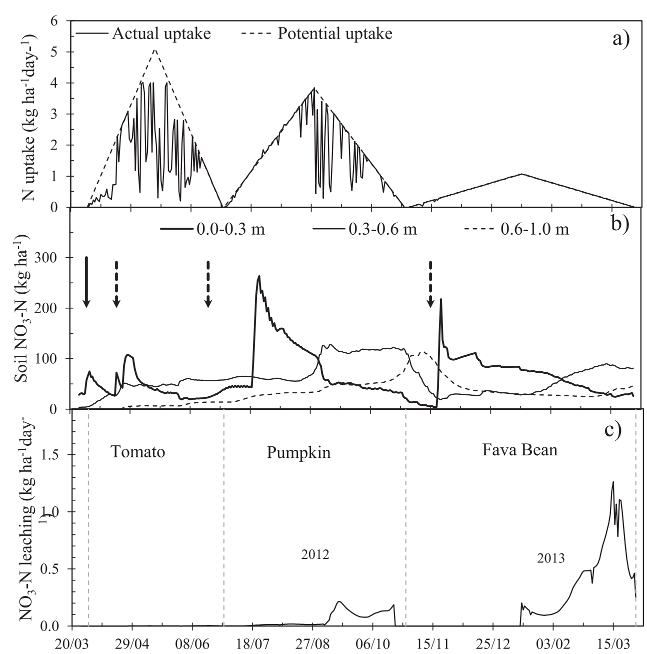

Fig. 7 – Predicted nitrogen balance components for the Granja Conv system (⟶organic fertilisation; - - -›mineral fertilisation).

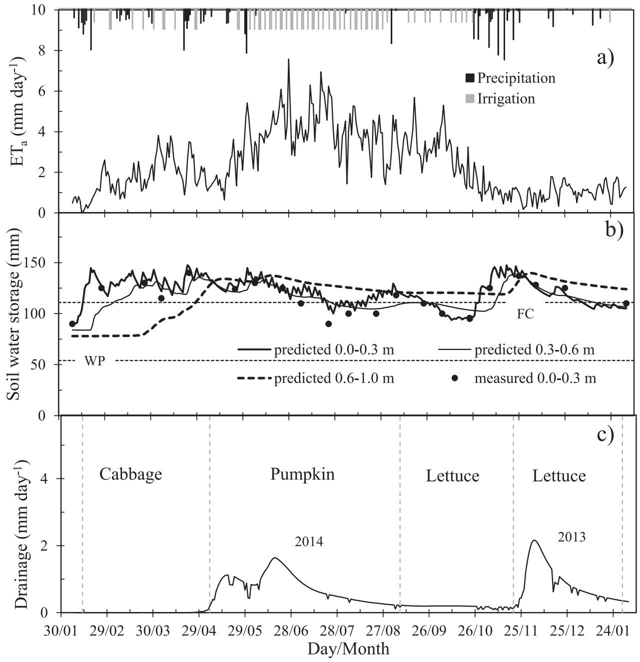

Fig. 8 – Water balance components for the Ajuda Org system (FC – field capacity, WP – wilting point).

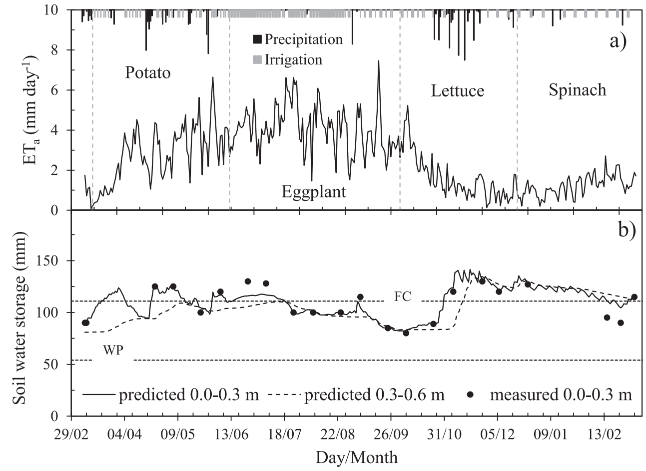

Fig. 10 – Water balance components for the Ajuda Conv system (FC – field capacity, WP – wilting point).

concentration of 230.3 and 358.7 mg NO_3^- l^{-1}. Since NO_3^- is a conservative ion, it is expected that this N will reach the groundwater where it will be diluted according to the water body properties. Nevertheless the continuous character of the existing practices may have led already to the high NO_3^- concentration is the wells (Table 4) and this negative impact can be expected to increase on a medium to long term basis. Other loss processes are not significant in Granja allotments due to the rapid N movement in depth.

Since drainage is reduced, the Ajuda soils tend to accumulate water and nitrates in the profile. The low infiltration rate introduced the potential for runof losses for both water and N. Nevertheless the major loss process in these vegetable production systems was the gaseous loss. Denitrification occurred due to the maintenance of high soil moisture during large periods of time and the accumulation of nitrates in the soil profile. Volatilisation was also a significant loss process, associated with the NH_4^+ present in the chicken manure. In the Ajuda allotments leaching losses have no significance in the global 1-year N budget. However, on a medium to long term basis, the nitrate accumulated in the lower soil layers and therefore not subject to denitrification, will eventually be leached out of the root zone and into groundwater. At the end of the studied period the nitrate accumulation in the soil profile was 324 and 518 kg $N-NO_3$ ha^{-1} for AConv and AOrg respectively. A similar situation was reported by Thompson, Martínez-Gaitan, Gallardo, Gimenez, and Fernández (2007) who presented mean soil mineral N contents of 527 kg ha^{-1} accumulated at the depth of 0.6 m in horticultural plots, showing the high pollution potential to the underlying aquifer. Immobilisation by the soil microbes contributed in 10% for the losses, except for GConv which shows a value of 20% in association with the high C:N ratio of the organic materials.

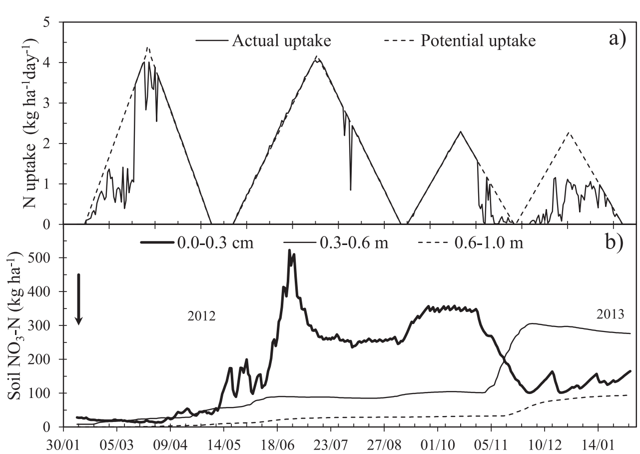

Fig. 9 – Predicted nitrogen balance components for the Ajuda Org system (⟶organic fertilisation; - - -›mineral fertilisation).

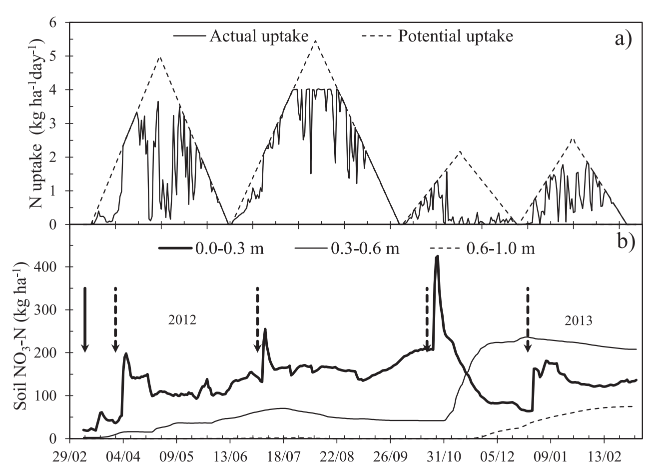

Fig. 11 – Nitrogen balance components for the Ajuda Conv system (⟶organic fertilisation; - - -›mineral fertilisation).

Table 10 – Non-fertiliser N sources as a percentage of uptake and N release rate from the amendments.

UA	Non fertiliser N sources (%)		Organic amendments N
	SOM	Irrigation	Release rate (kg N t^{-1} yr^{-1})
GOrg	4	0	19.4 with C:N = 14.3
GConv	12	35	9.2 with C:N = 20
AOrg	26	14	20.1 with C:N = 13.2
AConv	14	14	20.9 with C:N = 13

SOM is the soil organic matter.

5.3. *Model performance and sources of uncertainty*

There are significant interactions among the different components of the system. Previous studies with RZWQM (Cameira et al., 2005, 2007) showed that to achieve good simulation results for nitrate transport, good descriptions of soil water contents and fluxes and required, followed by good descriptions of the N transformations in the soil. In this study, the RZWQM predicted soil water storage for a 1-year crop cycle with an average RMSE of 5.5% ensuring some reliability in the prediction of drainage and consequently of the convective process transporting the NO_3^-. This reliability could be increased if the upper boundary flux, ETc (Figs. 4a, 6a, 8a, 10a), was also verified against field data. The partitioning of the measured SOM among the different pools was performed using the pool initialisation procedure of RZWQM followed by a long term simulation to equilibrate the pools. The interpool coefficients were adjusted until the predicted mineralisation matched the expected mineralisation for the experimental conditions. Therefore, in this study, the greatest uncertainty lies in the N transformations (nitrification, volatilisation and denitrification) since there are no NO_3–N and NH_4–N measurements for the verification of processes. Nevertheless, the results are consistent with the theoretical assumptions and with results presented by other authors. For example, predicted denitrification is comparable to other values simulated (Fang et al., 2012) or measured in the field (Meisinger & Randall, 1991). The higher volatilisation losses are associated with the NH_4^+ content of the different manures, as shown by Huijsmans, Hol, and Vermeulen (2003). Another source of uncertainty may be the fact that only four cases were studied, although we tried to incorporate the large amount of information provided by farmers in the survey. This information was *per se* subject to some variability and contradiction. Given the modelling uncertainties, the comparative discussion based upon the magnitudes, the temporal tendencies and the relations between variables should be favoured over the absolute values.

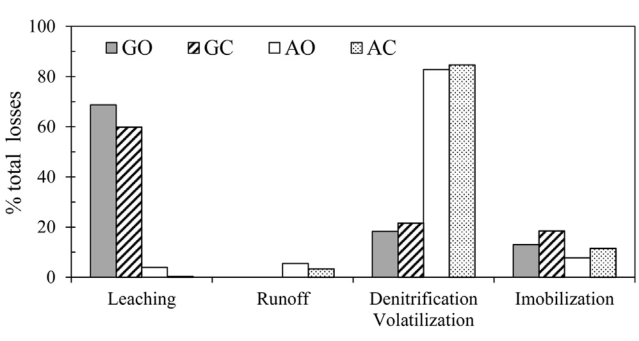

Fig. 12 – Relative importance of the pathways for N losses.

5.4. *Techniques for the reduction of leaching in the studied urban context*

The results of this study demonstrate that opportunities exist to improve the farmers' irrigation and fertilisation practices. The recommended techniques are: (1) To control leaching in spring/summer periods, a low cost technical solution easy to implement is the use of mechanical tensiometers capable of estimating the time for irrigation. By maintaining the SWS below FC, deep drainage will be reduced in the Granja allotments and gaseous losses will decrease in the Ajuda allotments; (2) During autumn/winter it is difficult to control SWS due to the random nature of the precipitation. Thus, the control of N leaching depends on the N surplus stored in the profile and available for leaching. N surplus can be reduced by including in the fertilisation calculations the non-fertiliser N sources; (3) The manure amounts and application times should follow the EU indications for the Nitrate Vulnerable Zones; (4) The use of simple calculation programs can help to establish the proportions of each organic component aiming for a C:N within the desired range of 20–30; and (5) Farmers are advised to discontinue mineral fertilisation for the conventional plots due to the adequate soil fertility levels.

Further research will allow the scaling-up of the NO_3^- leaching from the case-studies, through the calculation of the groundwater recharge for each site specific hydrogeology.

6. Conclusions

- In a general sense, the studied urban garden production systems were intensive, continuously cropped using high application rates of N and water. N inputs were derived mainly from organic amendments with different sources, having variable composition and different N release rates. Nitrate concentration measured in the wells that provided water for irrigation may indicate the existence of an imbalance in the water and N budgets.
- A number of individual management factors are likely contributing to appreciable N losses: (i) irrigation and N managements are based on the allotment user's experience, leading to excessive applications in comparison to crops requirements; (ii) the majority of the organic materials applied revealed inadequate C:N ratios; (iii) non-fertiliser N sources were not considered in the fertilisation planning;
- The RZWQM modelling allowed not only a detailed conceptual analysis of water and N balances in each system, but also led to the quantification of the N surpluses; the quantification of the N release rates of each fertilising mixture; and the identification of the major pathways of N losses in association with each agro system characteristics;
- The organic production system *per se* is not necessarily environmentally safer than the conventional production

system. The N load associated with the organic amendments can be very high if the C:N is too low as a result of an unbalanced composition of the organic mixture;

- The accumulated impact of these losses can be considerable in the context of long-term productivity, environment and human health, consisting in a potential groundwater contamination risk, so integrated water and fertiliser management is proposed. It is concluded that to make more efficient use of the N present in the manure, there is the need to understand the dynamics of mineral N release from the organic forms, function of the C:N ratio of the material and the ecosystem state variables like soil water and temperature. Modelling is suggested;
- Given the modelling uncertainties, comparisons based upon the magnitudes, the temporal tendencies and the relations between variables should be favoured over the reliance on absolute values.

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