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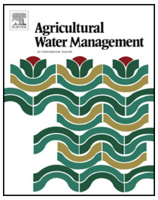

# Influence of irrigation and fertilisation management on the seasonal distribution of water and nitrogen in a semi-arid loamy sandy soil

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ABSTRACT

Increased use of irrigation on semi-arid sandy soils requires optimisation of irrigation and fertilisation practices to reduce water and nitrogen (N) losses. Field experiments were conducted on a semi-arid loamy sandy soil in two consecutive cropping periods, one in a cold-dry season (CP-cd) and one in a hot-wet season (CP-hw). The effects of individual treatment factors and their interactions, including two different irrigation methods (furrow – F or drip – D), two irrigation levels (full – $I_f$ or reduced – $I_r$) and two top dressing N fertiliser types (quick – $N_q$ or slow – $N_s$ release), on water and N distribution in the soil profile, potential water fluxes to the zone below the roots and N losses from the 0–90 cm soil profile were studied. The concentrations of NO3-N and NH4-N in soil water (from suction cups) and soil (from bulk soil samples) tended to be higher at greater depth in the treatments with lower soil water tension, resulting from the interactions between the factors F or D with $I_f$ and $N_q$, most probably resulting from net downward redistribution of N. The $I_rN_s$ treatments resulted in longer soil water NO3-N and NH4-N residence time at 30 and 60 cm depth, and throughout the two cropping periods NO3-N was higher in $N_s$ than in $N_q$ treatments. Potential faster downward water flux, and thus water losses and the N leaching risk, was concentrated to the first 50–75 days after sowing in $FI_r$ and $DI_r$ treatments, while it was spread throughout the cropping periods in $FI_f$ and $DI_f$. Hence, treatments $FI_fN_q$ and $DI_fN_q$ in both CP-cd and CP-hw resulted in the highest estimated N losses from the 0–90 cm soil profile. Based on these results, a combination of D irrigation, $I_r$ irrigation level and $N_s$ fertiliser type should preferably be applied, to avoid the risk of excessive water losses, downward N redistribution and subsequent leaching.

## 1. Introduction

Accurate knowledge of water and nitrogen (N) redistribution in soil is essential for proper design and management of irrigation and N fertiliser application options to safeguard sustainable farm practices (Wang and Xing, 2016a). Worldwide, irrigated agriculture contributes 40% of the food produced (WWAP, 2012), and it represents the major force controlling N dynamics in soil due to its impacts on the moisture content (Valé et al., 2007). In the soil system, N fertilisers are subjected to losses by a number of pathways, of which leaching, mainly in the form of nitrate ($NO_3^-$-N, hereafter NO3-N), is the most important. Therefore, proper management of irrigation and N fertiliser applications is essential, particularly in regions dominated by semi-arid soils, such as southern Mozambique. Sandy soils generally have higher internal drainage with lower water-holding capacity than finer-textured soils (McNeal et al., 1995). When combined with excessive irrigation (e.g. under traditional furrow irrigation), this is likely to result in N losses, with associated potential yield decreases and reduced water and nitrogen use efficiency (Rivera and Boochs, 2009).

In general, previous studies have indicated that N redistribution in the soil profile is intimately associated with the soil NO3-N concentration and the amount of water lost through deep percolation (Tamini and Mermoud, 2002; Gheysari et al., 2009; Jia et al., 2014). Ammonium-N ($NH_4^+$-N, hereafter NH4-N) is another form of N potentially lost in coarse-textured soils (Vitosh et al., 1995), yet to a lower degree than NO3-N. According to Deare et al. (1995), NH4-N redistribution in the soil profile can be expected to be fast following urea fertilisation. Nevertheless, a limited number of studies have assessed the downward movement of NH4-N in loamy sandy soils, while most research focuses on NO3-N. Thus, water and N management practices require improvements to increase both NO3-N and

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NH4-N residence time in the root zone, and thereby increase their availability for crops.

Various water and N fertiliser management practices have been suggested for sandy soils, including surface drip irrigation (Darusman et al., 1997; Arbat et al., 2013; Wang et al., 2014; Liu et al., 2015), application of slow or controlled-release fertilisers (Noellsch et al., 2009; Guan et al., 2014), multiple or split application of N fertiliser (Nakamura et al., 2004), reduced irrigation and reduced N fertiliser level (Jia et al., 2014; Sui et al., 2015) and a combination of organic and chemical fertilisers (Arbat et al., 2013; Omar et al., 2015).

Irrigation management is of greater importance than fertilisers in reducing N losses, and the use of drip irrigation has been shown to improve water and N use efficiency in maize production. In the case of excessive water application, however, such as high rainfall events, in combination with high N application has been associated with high NO3-N losses due to maintenance of high soil moisture content (Arbat et al., 2013). Furthermore, high frequency, low volume irrigation, e.g. drip irrigation, has been shown in some studies to result in greater deep percolation losses than low frequency, high volume irrigation, e.g. furrow irrigation (e.g. Behera and Panda, 2009). In other studies, drip irrigation has been found to be the best water application method for reducing water and N losses (e.g. Souza et al., 2009; Liu et al., 2015). Recognising the strong positive relationship between N leaching, on one side, and irrigation levels and N application rates, on the other (Sui et al., 2015), it has been suggested that for maize production, it may be possible to reduce NO3-N leaching from the root zone by split application of irrigation and N according to crop growth stage requirements (Jia et al., 2014).

The application of slow-release N fertiliser (e.g. poilyolefin resin-coated urea and isobutylidene diurea) to sandy soils potentially reduces N losses through leaching compared with quick-release N fertiliser (*i.e.* $NH_4NO_3$) (Wang and Alva, 1996). Furthermore, improvements in N use efficiency of up to 27% compared with conventional N fertilisers have been reported when slow-release N fertilisers are used in maize production in semi-arid areas (Guan et al., 2014).

Despite these advances, there are persistent risks of increased downward redistribution of water and N resulting in deep percolation and leaching of nutrients beyond the root zone (Ajdary et al., 2007; Sui et al., 2015). These risks require more research, especially in cases where applied and percolating water exceeds the water-holding capacity of the soil (Omar et al., 2015). There is still limited information on the effects of different irrigation and N fertiliser strategies on the magnitude of water and N redistribution and accumulation in the soil profile (Barakat et al., 2016; Wang and Xing, 2016), especially for coarse-textured soils (Sexton et al., 1996). Such information is essential to improve N budgets in different agro-climate conditions.

The objective of the present study was to assess, in a field experimental set-up, water and N redistribution, including potential fluxes to the zone below the roots, during two contrasting cropping periods, cold-dry and hot-wet, as affected by irrigation method, irrigation level and N fertiliser type.

## 2. Material and methods

### 2.1. Description of study area

The field experiments used in the present study were the latter two of four consecutive trials conducted from 2012 to 2015 on the same field plots located at the Faculty of Agronomy and Forestry Engineering experimental station in Sábie village, southern Mozambique (25°19′13″S; 32°15′53″E, 58 m above sea level). Results from two previous studies have been published in Chilundo et al. (2016) and Chilundo et al. (2017).

The site is characterised by a tropical steppe climate, corresponding to BSh in the Köppen classification (Peel et al., 2007), with two contrasting seasons, a cold-dry season from May to September and a hot-wet season from October to April (Reddy, 1984). Mean annual temperature is 23 °C, with a mean minimum of 11 °C in June and July, and a mean maximum of 34 °C in December and January, with a range of 2–39 °C (cold-dry season) and of 9–44 °C (hot-wet season). Mean annual rainfall is 580 mm and shows strong seasonal variation, with about 12% in the cold-dry season and 88% in the hot-wet season (Reddy, 1984). Total annual potential evapotranspiration frequently exceeds 1500 mm, with June and July having the lowest values, approximately 100 mm (Reddy, 1986).

The soil in the area consists of deep stratified alluvial deposits, with slope of 1–2%, classified as Eutric Fluvisols (FAO soil classification) (INIA, 1990). Before the establishment of trials plots, soil samples collected throughout the experimental site (0–80 cm depth) in four depth layers (i.e. 0–20, 20–40, 40–60 and 60–80 cm) indicated that soil texture ranged around the border between loamy sand and sandy loam. Furthermore, the organic matter content ranged between 0.1 and 2.1% and cation exchange capacity between 4.9 and 10.9 meq per 100 g. Dry bulk density ranged between 1.2 and 1.4 g $cm^{-3}$ in soil cores sampled in a pit (2 replicates per soil profile horizon, *i.e.* 20 cm layers) at the experimental site. Field capacity estimated from soil moisture observations in the experimental plots ranged between 17 and 23% (v/v) and permanent wilting point between 4 and 6% (v/v). Before establishment of the cold-dry period crop, total soil NO3-N ranged from 2.0 to 22.5 mg $kg^{-1}$ and soil NH4-N ranged from 2.5 to 23.2 mg $kg^{-1}$. In the central block, used here for detailed studies of soil water flux direction, the field capacity ranged between 17 and 24% (v/v) and the permanent wilting point between 4 and 6% (v/v).

### 2.2. Experimental design and cultivation practices

The field experiments included eight treatments, resulting from combination of two irrigation methods, two irrigation levels and two topdressing N fertiliser types arranged in a 2 × 2 × 2 factorial system in a randomised complete block design with three replicates (blocks). The three blocks were laid side by side and separated by a 2 m wide strip, while a 1 m strip separated the individual plots within each block. The size of each plot was 8 m × 8 m.

The experiments in the present study were established and monitored during two cropping periods (CP) to match the two annual growing seasons: one in the cold-dry season, May to September 2014 (CP-cd), and one in the hot-wet season, November 2014 to February 2015 (CP-hw). Irrigation methods were furrow (F) and drip (D). Irrigation levels were set to meet at least the crop water requirements ($I_f$) and reduced irrigation equalling 75% of $I_f$ ($I_r$), and the N fertiliser types were quick-release ($N_q$) and slow-release ($N_s$). The combined factors resulted in eight treatments assigned to each plot as follows: $FI_fN_q$, $FI_fN_s$, $FI_rN_q$, $FI_rN_s$, $DI_fN_q$, $DI_fN_s$, $DI_rN_q$ and $DI_rN_s$.

Medium maturation maize hybrid PAN67, which has a cycle of approximately 140 days to maturation in the cold-dry season and 110 days in the hot-wet season, was planted manually in all plots on 10 May in CP-cd and on 10 November in CP-hw. The spacing between plants was 30 cm, with a final density of 41,600 plants $ha^{-1}$ in all plots.

All plots were treated equally except for the management of irrigation and N fertiliser type. Conventional tillage using a disc plough to a working depth of 20–25 cm, followed by disc harrowing, was used for soil preparation before crop establishment in CP-cd, while before establishment in CP-hw no soil preparation was done other than manual weeding. Pests were controlled by spraying chemi-