Nitrogen use efficiency as an indicator for monitoring the environmental sustainability of maize production in central Chile

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Abstract
The main purpose of this study was to evaluate the Nitrogen Use Efficiency (NUE) as an indicator for monitoring the environmental sustainability of maize production in the O'Higgins Region in central Chile. Additionally the NUE indicator was used for evaluating the extension services offered for a Clean Agreement Program (CAP) developed for the Chilean Government for the maize-farmers in this Region. A crop management survey was carried out in 80 maize fields during the season 2014-2015, where most of the NUE values were less than 50% using traditional farmer N fertilisation rates, being related to N over-fertilisation. For the 2016-2017 season, 85% of the NUE values would be between the two NUE references values of 50% and 90% if a N recommendation scenario based on a mass N balance by the CAP is applied by the maize-farmers. Thus NUE showed that it is necessary to reduce the N input for improving the environmental sustainability of maize production in this Region.

Key Words
Compound nitrogen fertilizer, Nitrate leaching, Mass N balance, Urea

Introduction
In Chile during the 2014-2015 season, maize (*Zea mays* L.) covered approximately 120,000 ha, producing 1.5 million tons of grain. Maize represented 20% of the total annual crop surface in the country with a mean yield of 13 ton ha^{-1}, one of the highest yielding in the world. This is largely due to the favourable Mediterranean climate conditions of temperature and solar radiation. Maize production in Chile is predominantly for domestic consumption, and is located mainly in three central Regions: O'Higgins, Maule and Metropolitan. It is cultivated mainly on flat soils located in alluvial terraces (Casanova et al 2013), under conventional irrigation systems during spring-summer (September-April). These production systems usually use high nitrogen (N) fertilisation rates between 350 and 560 kg N ha^{-1}, together with low irrigation efficiency (<45%) (Nájera et al 2015).
Although it is possible for a substantial amount of applied N to be leached by excessive irrigation during the crop growing season (spring-summer), a significant amount of residual N may still be present in the soil in autumn-winter. This N surplus poses a high risk of nitrate (NO_3^-) leaching during the traditional fallow (autumn-winter) period, that receives ~65% of annual rainfall on average. In Mediterranean zones of Chile there are further concerns because N over-fertilisation in irrigated maize fields can be associated with a high risk of diffuse pollution of water bodies (Corradini et al 2015). Particularly important are coarse textured soils cultivated with maize that are more prone to N leaching due to the high percolation rate and low water retention capacity of soils (Salazar et al 2013). Similarly, in other areas in the world, irrigated maize fields with high N doses have been highlighted as a source of N diffuse pollution (Quemada et al 2011). Particularly, dissolved inorganic N (DIN) forms, such as NO_3 and ammonium (NH_4), have been cited as the main sources of N leaching in agricultural systems, which have focused attention on the study of DIN in agricultural soils (Murphy et al 2000).
The EU Nitrogen Expert Panel (2015) has proposed Nitrogen Use Efficiency (NUE) as an indicator of N utilization in agriculture and food systems. It is a term refers to the ratio of the amount of N output in harvested product to the amount of N applied (input) as fertilizer. The main aim of this study was to evaluate the NUE as an indicator for monitoring the environmental sustainability of maize production in the O'Higgins Region in central Chile. Additionally the NUE indicator was used for evaluating the extension services offered for a Clean Agreement Program (CAP) developed for the Chilean Government for the maize-farmers in this Region.

Material and methods

Site description

The study was carried out on 80 maize fields located in the O'Higgins Region in central Chile (Figure 1). Maize was sown in spring (September-October 2014) and harvested in autumn (March-April 2015). Usually, a commercial hybrid maize adapted to this area is used for an anticipated stand of about 95,000 plants ha^{-1} (Nájera et al 2015). In these fields the maize grain yields ranged from 11 to 19 t ha^{-1}. During the growing season the maize was irrigated using a furrow system with low water use efficiency (<45%). Water application with irrigation ranges between 10.000 and 20.000 m^3 ha^{-1} during the cropping cycle.
All fields included in this study have a climate described as semi-arid Mediterranean, with hot summers and relatively cold winters, a mean annual air temperature of 15 ºC (29 ºC in January and 5ºC in July) and a mean annual precipitation of around 700 mm, mostly falling between May and October.

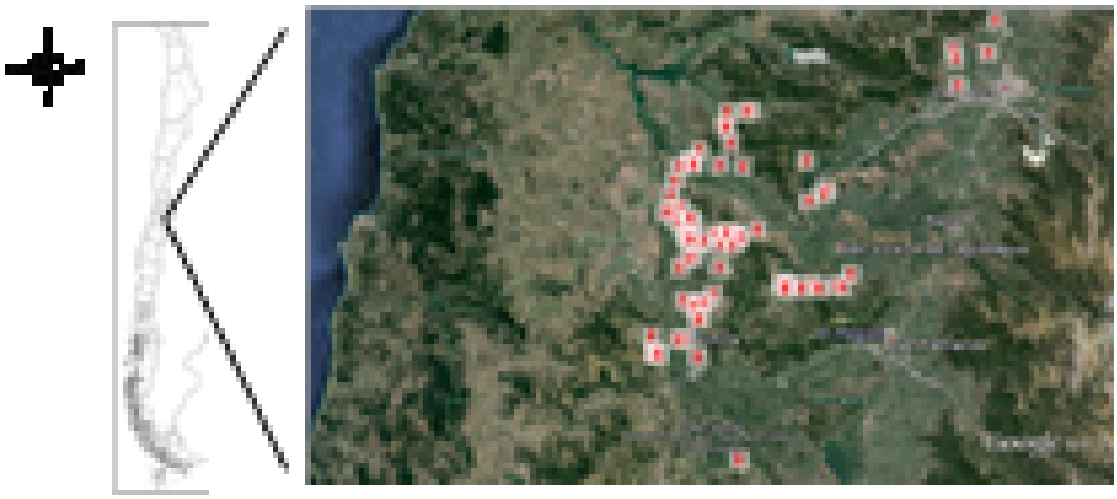

Figure 1. Location of the maize fields in the O'Higgins Region.

Optimum dose of nitrogen fertiliser

A survey regarding maize yields, fertilisation and soil management from September 2014 to April 2015 was conducted for each field. During this time farmers applied two types of fertilisers: a mixed fertiliser, for instance 25-10-10 (%N - $\%P_2O_5$ - $\%K_2O$, respectively) at planting using subsurface bands; and urea (46-0-0) as side-dressing between V4 and V6 vegetative stages. In 2015 these farmers signed up for a voluntary Clean Agreement Program (CAP) developed by the Chilean Government for the maize-farmers in this Region. One of the objectives of the CAP was to increase the NUE and to reduce N pollution. An extension service was developed for calculation of optimum dose of N fertiliser on each field. A comparison was conducted between common farmer fertiliser rates and recommended rates. The recommended N rate was calculated based on maize demand by the N dose Stanford's classic approach (Stanford 1973), that includes a mass N balance for assessing crop N fertiliser needs by considering N uptake at a specific dry matter yield level and N contributions from non-fertiliser sources. Thus the recommended N rate of fertiliser was calculated according to equation 1:

$$N\ demand\ (kg\ N\ ha^{-1}) = \frac{Y \times \left(1 - \frac{H}{100}\right) \times \frac{INR}{100}}{HI} \qquad \text{(Eq. 1)}$$

where Y is the grain yield (kg ha^{-1}), H is grain moisture content (%), INR is the internal N requirement (%) and HI is harvest index (-). Y was estimated for each field according to site conditions, including maize hybrid yield and soil factors such as soil depth and soil compaction. In addition, N rate per hectare is calculated as equation 2:

$$N\ rate\ (kg\ N\ ha^{-1}) = \frac{N\ demand\ (kg\ N\ ha^{-1}) - Net\ N\ mineralization\ (kg\ N\ ha^{-1})}{\frac{N_{Ef}}{100}} \qquad \text{(Eq. 2)}$$

where N_{Ef} is the N fertiliser efficiency, mostly depending on soil type and irrigation system (Chilean studies suggest N_{Ef} values range from 50% to 65%); N_{demand} was calculated using equation 1; and the net N mineralisation potential of soils that depend on soil management and N recycling (Nájera et al 2015).

Nitrogen Use Efficiency indicator

The NUE was calculated in each field according the equation 3 proposed by the EU Nitrogen Expert Panel (2015):

$$NUE\ (\%) = \frac{N\ output\ in\ harvested\ product}{N\ input} \times 100 \qquad \text{(Eq. 3)}$$

where *N output in harvested product* (maize grain) was calculated considering the grain yield and N concentration in grain, whereas *N input* considered only N fertilisation. The NUE was used for comparison of the N fertilisation carried out by the farmers during the season 2014-2015 versus a scenario in which the recommended N rate by the extension service was applied for the season 2016-2017. EU Nitrogen Expert Panel (2015) defined that the desired NUE value is between 50% and 90%, whereas a NUE < 50% indicates an inefficient N uses and points to high N losses and a NUE > 90% indicates soil N depletion.

Results

Figure 1 shows the NUE results for maize fields in the O'Higgins Region during the season 2014-2015 (n=80). The mean NUE was 45%, ranging from 27% to 99%, where most of the NUE results (76% of the NUE values) were less than 50%. Therefore most farmer N rates exceeded yield potential indicating that residual N, mainly NO_3^-, may leach if there is sufficient water to percolate below the root zone. As a result, N over-fertilisation increase the risk of N soil accumulation and nitrate leaching. In addition, runoff from furrow irrigation can increase the risk of movement of residual N from the fields towards surface and subsurface waters during the growing season (Corradini et al 2015).

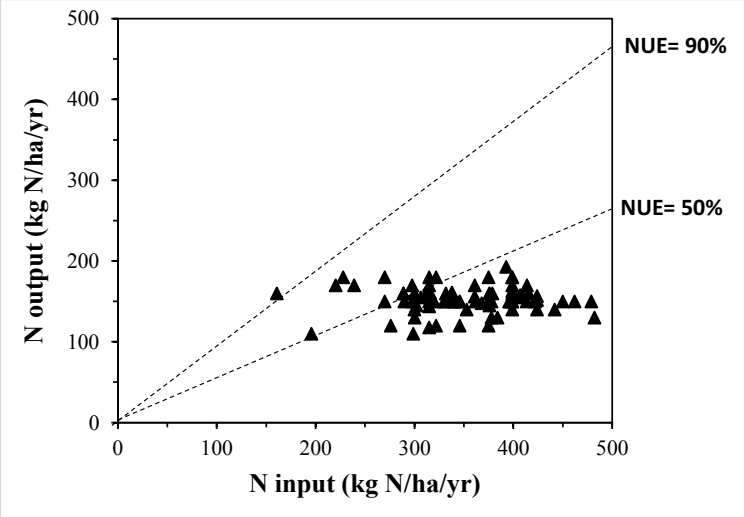

Figure 1. Nitrogen use efficiency (NUE) in the maize fields in the Chilean O'Higgins Region during the season 2014-2015 (n=80). The slope of the diagonal wedge represent a range of desired NUE between 50% and 90% according to EU Nitrogen Expert Panel (2015).

In contrast, using equations 1 and 2 the extension service by CAP recommended a decreased in N fertilizer input for the crop season 2016-2017 compared to season 2014-2015. Under this scenario most of the NUE would decrease to values between the two NUE reference values of 50% and 90% (85% of the NUE values) (Figure 2). Clearly, most of maize fields were over-fertilised during season 2014-2015, and the N surplus ranged between 16 and 325 kg ha^{-1}. However, it will be necessary to evaluate the maize yield at the end of the crop season (April 2017) to determine the impact of reducing N application on the N output.

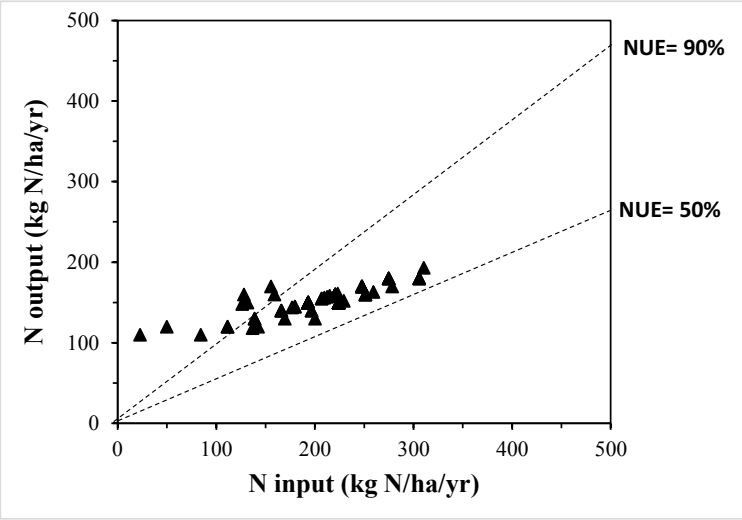

Figure 2. Nitrogen use efficiency (NUE) in the maize fields in the Chilean O'Higgins Region using a scenario of the recommended rate of nitrogen fertiliser by the extension service for the season 2016-2017 (n=80). The slope of the diagonal wedge represent a range of desired NUE between 50% and 90% according to EU Nitrogen Expert Panel (2015).

Conclusion

Most of the NUE values were less than 50% using traditional farmer N fertilisation rates. That implies an over-fertilisation with N and suggests that maize fields are an important source of non-point N pollution. Thus NUE showed that it is necessary to reduce the N input for improving the environmental sustainability of maize production in the O'Higgins Region in central Chile. In contrast, 85% of the NUE values would be between 50% and 90% if an N recommendation scenario based on a mass N balance proposed by CAP were applied by the maize-farmers.

Acknowledgements

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