

PRECISION NITROGEN MANAGEMENT AND GLOBAL NITROGEN USE EFFICIENCY

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ABSTRACT

Traditionally, nitrogen (N) fertilizers have been applied uniformly across entire field while ignoring inherent spatial variation in crop N needs within crop fields. This results in either too little or too much application of N in various parts of the fields. Too little N reduces yields while too much N reduces nitrogen use efficiency (NUE). The objective of this study was to analyse the global consumption of N fertilizer and current status of NUE of three main cereal crops (wheat, maize and rice) for major fertilizer consuming countries and the world. Currently, 100 million tonnes of N per annum is applied as fertilizer for agricultural production worldwide, out of which 50% is consumed in production of three major crops – wheat, maize and rice. China is the largest consumer of N fertilizer followed by India, USA and EU; and together these countries consume about 70% of world fertilizer N. While the global NUE for major cereal crops (wheat, maize and rice) is still low, there is a potential of increasing NUE as evidenced by N fertilizer consumption trends and the adoption of precision N management strategies in the USA over the last 10-15 years. Based on current cost of US\$1000 per metric ton of N fertilizer, a 10% increase in NUE of these major crops would result in savings of about US\$5 billion per year and substantial improvement in environmental quality.

Keywords: Nitrogen fertilizer, nitrogen use efficiency (NUE), precision nitrogen management

INTRODUCTION

Application of nitrogenous fertilizers in crop fields has played a major role in enhancing food production across the globe. It is estimated that almost half of the world's population is currently fed as a result of increased crop productivity due to the use of inorganic nitrogen fertilizers (Erisman et al. 2008).

Currently, 100 million tonnes of nitrogen (N) per annum is applied as fertilizer for agricultural production worldwide, out of which 50% is consumed in production of three major crops – wheat, maize and rice (Heffer 2009). However, only 30-50% of this applied nitrogen is recovered by crop plants (Cassman et al. 2002). Thus, more than 50% of the N not assimilated by plants becomes a potential source of environmental pollution – groundwater contamination, eutrophication, acid rain, ammonia redeposition, global warming and stratospheric ozone depletion (Ladha et al. 2005). While N losses cannot be avoided completely, there is certainly a scope to minimise losses with new and innovative precision N management techniques and technologies. Based on current cost of US\$1000 per metric ton of N fertilizer (Indexmundi 2012), a 10% increase in NUE of major crops (wheat, maize and rice) would result in savings of about US\$5 billion per year and substantial improvement in environmental quality.

The current world population of 7 billion people is expected to increase to 8 billion by 2025 (UN 2011). The cropping systems that produce maize, rice and wheat are likely to play bigger role in meeting this global challenge of increased food demand (Cassman et al. 2002). NUE generally follows law of diminishing returns because incremental gains in yield and N uptake are much larger at low rates compared to higher N application rates. For example, Dobermann (2005) reported a decrease in NUE from 77% to 41% when N rates were increased from 75 to 275 kg ha⁻¹ in maize production. The grain yield was lower at higher NUE and incremental gains in yield decreased from 44 to 16 kg grain per kg of N applied. Thus, the biggest challenge today is to increase both the NUE and grain yields of wheat, maize and rice.

Traditionally, nitrogen (N) fertilizers have been applied uniformly across entire field while ignoring inherent spatial variation in crop N needs within crop fields (Khosla et al. 2010). This results in either too little or too much application of N in various parts of the fields. Too little N reduces yields while too much N reduces nitrogen use efficiency (NUE). Also, a large percentage of fertilizer (around 75%) is either applied prior to or at planting resulting in inadequate synchrony between supply and demand of N by crop plants (Cassman et al. 2002). In many developing countries, often a region-based single fertilizer recommendation is prescribed to farmers that do not take into account the variations in the indigenous N supply from their specific fields (Cassman et al. 2002). To overcome the limitations of traditional N management practices, scientists all over the world have conducted research during the last 15-20 years to develop precision nitrogen management strategies (e.g. Peng et al. 1996;

Khosla et al. 2002; Raun et al. 2002; Inman et al. 2005; Khurana et al. 2007; Li et al. 2009; Schmidt et al. 2011)

The objective of this study was to analyse the global consumption of N fertilizer and current status of NUE of three main cereal crops (wheat, maize and rice) for major fertilizer consuming countries and the world.

GLOBAL STATUS OF N CONSUMPTION AND NITROGEN USE EFFICIENCY

World's total fertilizer consumption of major nutrients, Nitrogen (N), Phosphorus (P) and Potassium (K) in 2007-2008 was about 169 million tonnes, out of which N fertilizer contributed about 100 million tonnes (Heffer 2009). It is estimated that about 55% of world's N fertilizer was applied to cereal crops (Fig. 1). Wheat contributes to 17.3% followed by maize (16.8%) and rice (15.6%). Only 5.1% of world's N consumption was for other cereals such as barley, oats, rye, sorghum and millet. Fruits and vegetables are another large consumer of N fertilizer accounting for 15.6% of total use. Oilseed, cotton and sugar crops represent 6.3%, 3.9% and 3.4% of global fertilizer N consumption, respectively. China is the largest consumer of N fertilizer followed by India and USA. EU countries consume 11.6% of world nitrogen. Together, China, India, USA and EU consume about 70% of world fertilizer N (Heffer 2009)

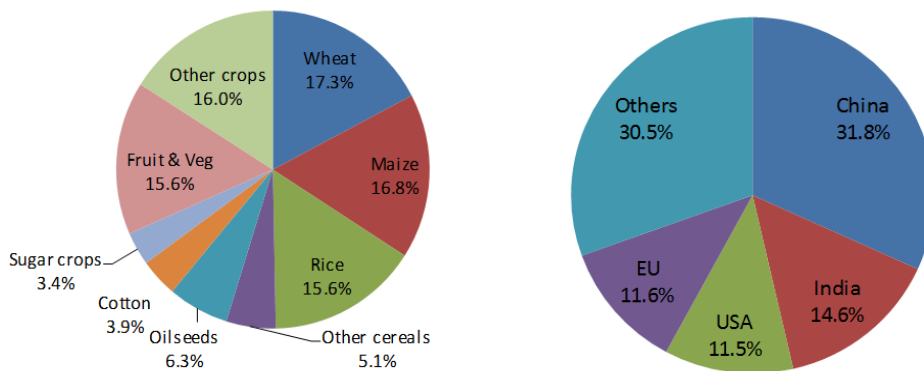


Fig. 1 Global nitrogen fertilizer use in 2007-2008 (Data sourced from Heffer 2009)

Nitrogen use efficiency (NUE) has been defined in many different ways in the literature. Ladha et al. (2005) indicated a total of 18 different measures of NUE. However, four indices of NUE are commonly used in agronomic trials (Dobermann 2005):

1. Partial factor productivity (PFP) defined as kg harvest product per kg N applied

2. Agronomic efficiency (AE) defined as kg yield increase per kg N applied
3. Physiological efficiency (PE) defined as kg yield increase per kg increase in N uptake from fertilizer
4. Recovery efficiency (RE) defined as kg increase in N uptake by the crop per kg N applied.

The first three indices relate to production efficiency where the output is harvested crop product and the input is N. However, the fourth index (RE) more accurately reflects the NUE as it gives the ratio of output N to input N indicating how well the given N-management strategy performs in recovering the applied N. RE is commonly measured by establishing plots with and without application of nitrogen and is calculated using Eq. 1.

$$RE = \frac{U_N - U_o}{F_N} \quad (1)$$

where:

U_N = total plant N uptake in aboveground biomass at maturity (kg ha^{-1}) in a plot that received N

U_o = total plant N uptake in aboveground biomass at maturity (kg ha^{-1}) in a plot that received no N

F_N = amount of fertilizer N applied (kg ha^{-1})

As it is difficult to conduct extensive on-farm studies to determine RE for various crops grown in different parts of the world, Raun and Johnson (1999) theoretically estimated NUE (equivalent of RE based on grain N) for world cereal grains by using Eq. 2. They assumed that 50% of the total N removed by grains was supplied by soil and rainfall.

$$NUE = \frac{N_{removed} - (N_{soil} + N_{rain})}{N_{applied}} \quad (2)$$

where:

$N_{removed}$ = total N removed in cereal grains (kg)

N_{soil} = N removed in cereal grains coming from the soil (kg)

N_{rain} = N removed in cereal grain that deposited in the rainfall (kg)

$N_{applied}$ = fertilizer N applied to cereals (kg)

By adopting the methodology described by Raun and Johnson (1999) and using the 2007-2008 data related to fertilizer use by crop from the International Fertilizer Industry Association (Heffer 2009) and the 2008 crop production statistics reported by the Food and Agriculture Organization (FAO 2011), the

NUE of main crops was estimated for the major fertilizer consuming countries and for the world (Table 1). Raun and Johnson (1999) did not take into account the N uptake by crop residue. However, review of literature (e.g. Waiss et al. 1972; Leask et al. 1973) revealed that there is a significant amount of N content in wheat straw, rice straw and maize stover. Thus, the NUE values presented in Table 1 are based on total N uptake in grain and crop residue. Grain to straw ratio was assumed to be 1:1. The following parameters were used in calculating NUE:

- Nitrogen content of wheat grain = 2.13% (Raun and Johnson 1999)
- Nitrogen content of maize grain = 1.26% (Raun and Johnson 1999)
- Nitrogen content of rice grain = 1.23% (Raun and Johnson 1999)
- Nitrogen content of wheat straw = 0.86% (Waiss et al.1972)
- Nitrogen content of maize stover = 0.72% (Leask et al.1973)
- Nitrogen content of rice straw = 0.56% (Waiss et al.1972)

Table 1. Nitrogen use efficiency of main agricultural crops for the major fertilizer consuming countries and the world.

Country/Region	Nitrogen use efficiency (%)			
	Wheat	Maize	Rice	Overall
China	39	33	31	34
India	38	53	30	35
USA	66 (74)*	56 (61)*	32	57
EU	70	45	51	62
World	59	49	39	49

*Based on 2010 grain production and N consumption data.

NUE varies from 39 to 70% for wheat, 33 to 56% for maize, and 30 to 51% for rice. The overall NUE for these major three crops was the lowest in China (34%) and highest in EU (62%). The world NUE values are 59, 49 and 39% for wheat, maize and rice, respectively. The overall NUE for major cereal crops (wheat, maize and rice) in USA and EU are 23% and 28% greater than that in China which is reflective of the more efficient production practices in advanced countries including adoption of precision nitrogen management strategies in these countries

CONCLUSIONS

To overcome the limitations of traditional N management practices; improve NUE in crop production; and protect environmental quality, scientists all over the world have conducted research during the last 15-20 years to develop precision nitrogen management strategies. These developments have helped in improving the global NUE of three major crops (wheat, maize and rice). Of the 100 million tonnes of current world fertilizer N consumption, 50% is consumed in production of these three crops. Overall NUE values for China and India are 34% and 35%, whereas these are 57% and 62% for the USA and EU, respectively. Comparative NUE data between USA, EU, China and India clearly shows that

there is a great potential in improving NUE worldwide by adopting precision N management strategies.

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