The 4Rs in a Latin American Context
Right Source at Right Rate, Right Time, and Right Place [1]

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Sustainable development is recognized to consist of three components: economic, social, and environmental. Every one of these components is essential to sustainability. The 4Rs Nutrient Stewardship is a framework for nutrient use developed by the fertilizer industry to provide for sustainability.

The 4Rs Nutrient Stewardship is an innovative approach to best management practices (BMPs) for fertilizers and other nutrient sources (crop residues, manure, recycling products, amendments, and biological fixed N_2), which ensures that the right source is applied at the right rate, right time, and right place (Bruulsema et al., 2008; Bruulsema et al., 2009; IFA, 2009) (**Figure 1**).

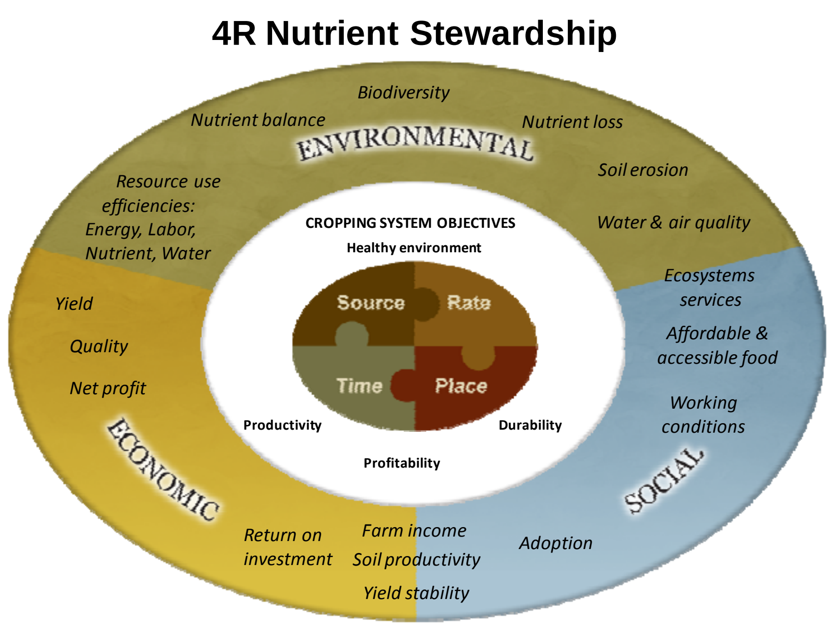

Figure 1. The 4R Nutrient Stewardship. Fertilizer use BMPs—applying the right nutrient source at the right rate, time, and place—integrate with agronomic BMPs selected to achieve cropping system management objectives of productivity, profitability, durability, and health of the biophysical and social environment. A balanced complement of performance indicators can reflect the influence of fertilizer BMPs on the economic, social, and environmental goals for sustainable development (Bruulsema et al., 2008; IFA, 2009).

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The 4Rs Nutrient Stewardship allows for (Bruulsema et al., 2009):

- Selecting the "right" source, rate, time and place for sustainable production
- Checklist for proper fertilization practices and opportunities to improve
- Balancing the effort among the 4 "rights"
- Contributing to the fertilizer industry in supporting its delivery and distribution role
- A clear and simple communication with the society

Fertilizer use BMPs are based on scientific principles, interdependent, and interlinked with a set of best agronomic management practices applied in the cropping system. None of the BMPs can be right if one is wrong, and more than one combination of source, rate, place and time would be right for any specific field and season.

The adoption of fertilizer BMPs improves resource and input use efficiencies, i.e. balanced nutrition improves water use efficiency in dryland cropping systems (**Figure 2**). Also, the effects of applying the 4Rs Nutrient Stewardship last beyond the immediate harvest by improving soil fertility and productivity (**Figure 3**).

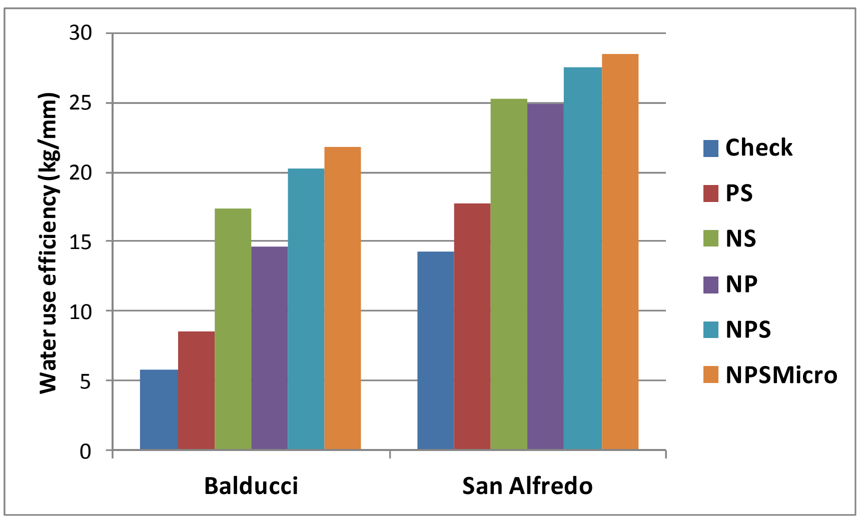

Figure 2. Water use efficiency in maize for six fertilization treatments in two sites of the Nutrition Network CREA Southern Santa Fe in the 2010/11 growing season. Source: CREA Southern Santa Fe-IPNI-ASP.

Fertilizer use BMPs in the Southern Cone of Latin America

In the following paragraphs, some examples of BMPs, and the scientific principles associated, for the Southern Cone region of Latin America, with emphasis in the Pampas region of Argentina, are described. Further information on BMPs for nutrient use is available at Echeverria and Garcia (2005), Melgar and Diaz Zorita (2008), Garcia and Salvagiotti (2010), Alvarez et al. (2010), and Garcia and Correndo (2011).

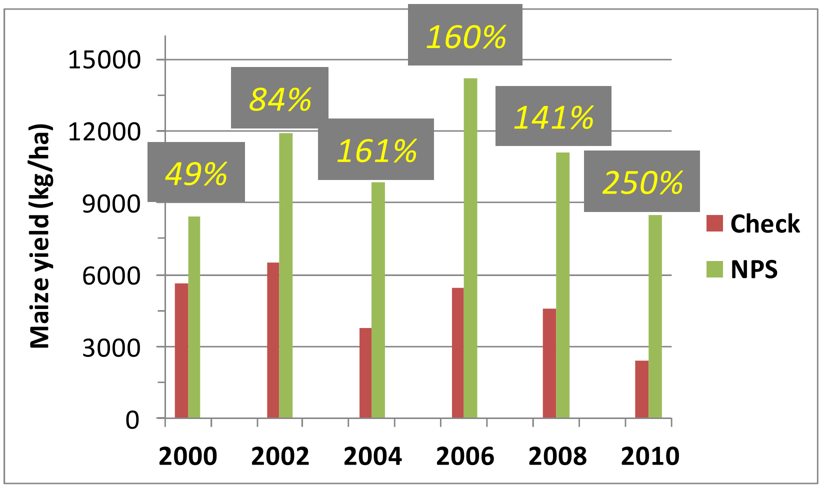

Figure 3. Maize grain yields from 2000 to 2010 in the Check and NPS treatments at the Balducchi site of the Nutrition Network CREA Southern Santa Fe. The numbers in the boxes indicate the yield difference (in percentage) between both treatments. Source: CREA Southern Santa Fe-IPNI-ASP.

1. Right rate

1.1. Soil test calibration for K at Uruguay

Potassium deficiencies have been detected in the last years in field crops at several areas of Uruguay (Cano et al., 2007; Bautes et al., 2009; Garcia et al., 2009). Initial soil test calibration has indicated a critical range of exchangeable K of 0.34 meq/100 g (equivalent to 133 mg/kg), below which there is a high probability of response to K fertilization (Barbazán et al., 2011) (**Figure 4**). This calibration allows to identify fields which would need K application. Current research is orientated to the evaluation of time and place alternatives for different cropping systems.

1.2. Soil available N at planting or during the growing season in the Pampas

The evaluation of available (inorganic) N at planting time has been a useful tool to determine fertilizer N needs in sub humid and semiarid regions of the world. In a particular area, the level of available N at planting (NO_3-N at 0-60 cm at planting + N fertilizer) above which no response to fertilizer N is expected can be estimated (critical level). This methodology has been calibrated with success in several areas of the Pampas region of Argentina for wheat and maize, Different critical N levels have been obtained according to the crop (wheat or maize), yield goal and soil and climate conditions of the area (**Table 1**).

Nitrogen fertilizer rates (Nf) are then estimated from the difference between the critical level and the amount of NO_3^--N determined before planting:

$$Nf = CL - X$$

where Nf is the amount of fertilizer N to be applied, CL is the critical level, and X is the amount of NO_3^--N in the soil at 0-60 cm depth.

Soil N determinations during the growing season have been also calibrated to estimate N fertilization needs for wheat and maize. In wheat, Barbieri et al. (2008) have estimated a critical level of 126 kg/ha nitrate-N, 0-40 cm at tillering for grain yields of ca. 5000-5500 $kgha^{-1}$ in southeastern Buenos Aires. In maize, several researchers evaluated the pre-sidedress nitrate test developed by Magdoff et al. (1984) in the US. Depending on grain yield and water availability, critical levels above which grain yield response to N is low or nil were 15 to 27 mg/kg nitrate-N at a 0-30 cm depth (Garcia et al., 1997; Sainz Rozas et al., 2000, Salvagiotti, 2004). Recent research has shown that N mineralization determined in short-term anaerobic incubations might contribute to improve the reliability of planting or pre-sidedress soil N tests in maize (Sainz Rozas et al., 2008).

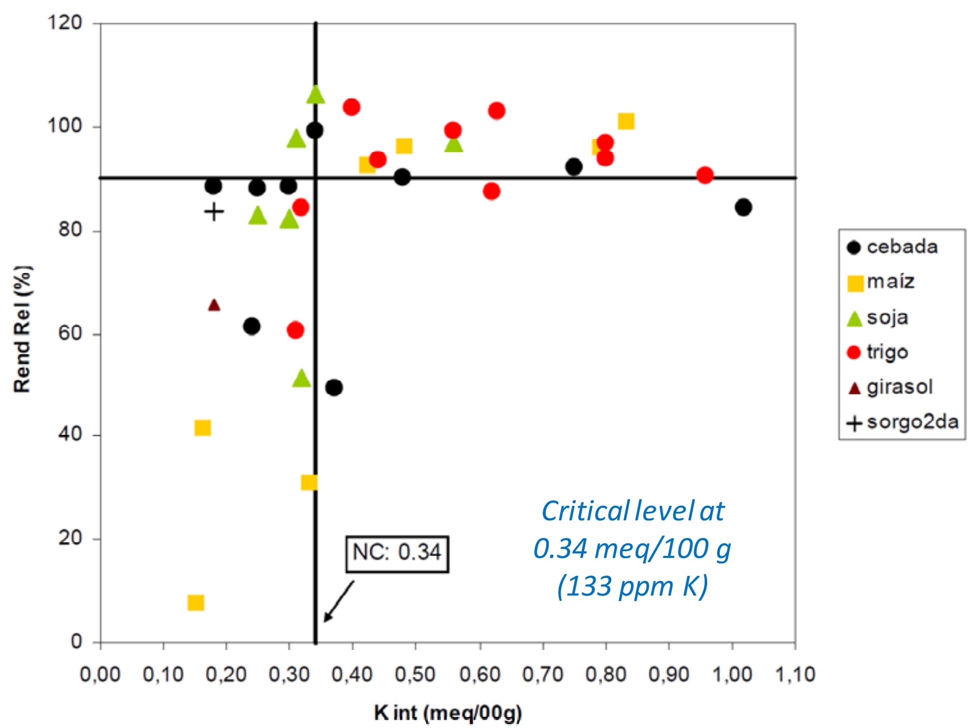

Figure 4. Soil test calibration for K at Uruguay indicating a high probability of K response below the critical level of 0.34 meq/100 g (equivalent to 133 mg/kg) (Barbazan et al., 2011).

Table 1. Critical levels of available N at planting (NO_3^--N, 0-60 cm depth) for wheat and maize in different areas of the Pampas with different expected yields.

Area	Critical level (NO_3^--N, 0-60 cm + fertilizer)	Expected yield	Reference
	-------- kg ha^{-1}	--------	
		Wheat	
Southeastern Buenos Aires	125	3500	González Montaner et al., 1991
Southeastern Buenos Aires	175	5000-5500	González Montaner et al., 2003
Central and South Santa Fe	92	3500-4000	Salvagiotti et al., 2004
Southern Santa Fe and Córdoba	100-150	3200-4400	García et al., 2010
		Maize	
Northern Buenos Aires	150	9000	Ruiz et al., 2001
Northern Buenos Aires	150-170	10000	Alvarez et al., 2003
Central and South Santa Fe	135 162	< 9500 > 9500	Salvagiotti et al., 2004
Southern Santa Fe and Córdoba	150-200	10000-11000	García et al., 2010

1.3. Diagnosis of P fertilization in grain crops at Argentina

The diagnosis of P fertilization in Argentina is based on soil testing before planting (Bray 1-P at 0-20 cm). Critical levels vary according to the crop (**Table 2**). Rates of P fertilization depend on the criteria of the farmer/consultant: i) build-up and maintenance, or ii) sufficiency levels (Echeverría and García, 1998; Ciampitti et al., 2009). Studies in different soils in Argentina indicated rates of 3 to 10 kg P/ha in order to increase soil P-Bray 1 by 1 mg/kg (Rubio et al., 2007; Ciampitti et al., 2009), depending on the initial soil P-Bray 1 level, soil texture, grain or forage P removal, and time from fertilization.

Table 2. Critical levels of soil P Bray 1 (0-20 cm) for wheat, soybean, sunflower and maize in the Pampas region of Argentina.

Crop	Critical level (mg/kg)	Reference
Wheat	15-20	Echeverría and García, 1998; García, 2007; Barbagelata, 2011
Soybean	9-14	Echeverría and García, 1998; Gutiérrez Boem et al., 2002; Díaz Zorita et al., 2002; Fontanetto, 2004
Sunflower	10-15	Díaz Zorita, 2004
Maize	13-18	García et al., 1997; Ferrari et al., 2000; Berardo et al., 2001; Garcia et al., 2010; Barbagelata, 2011

2. Right time

2.1. N fertilization in wheat for the Pampas region

The period from planting to the end of tillering is usually dry for most of the wheat producing area of Argentina. Therefore, early N applications usually result in high N use efficiencies (Melchiori and Paparotti, 1996; Díaz Zorita, 2000). However, in areas in the southeast of the Pampas, winter precipitation may increase nitrate leaching, and in several years N use efficiency would be improved by N topdressing at tillering compared to pre-plant or planting applications (Melaj et al., 2003; Barbieri et al., 2008) (**Figure 5**).

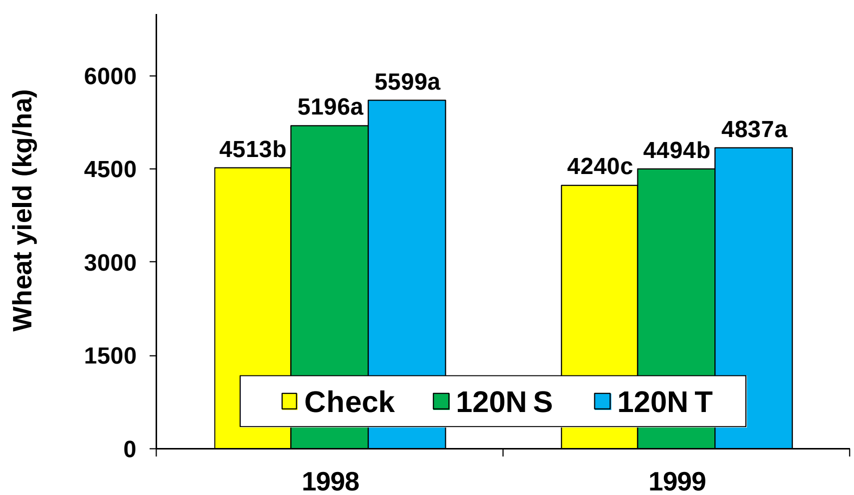

Figure 5. Wheat grain yield for different N rates and application times (S at sowing; and T at tillering) in two growing seasons at the southeastern Buenos Aires province, Argentina. (Melaj et al., 2003).

2.2. N fertilization for maize in the Pampas

Nitrogen applications to maize are carried out before planting, at planting, or up to V5-6 stage. Research has shown that fertilization around V5-6 usually have greater N use efficiency than early applications (Sainz Rozas et al., 1999).

3. Right source

3.1. N fertilization for maize in the Pampas

Differences in N use efficiency in maize among N fertilizers have been observed under surface applications, especially at V5-6, because of NH_3-N volatilization losses from surface-applied urea (García et al., 1999; Sainz Rozas et al., 1999; Salvagiotti and Vernizzi, 2006). Ammonia-N losses are lower with dribble UAN than surface-applied urea improving N use efficiency. However, all N fertilizer sources show similar efficiencies when they are incorporated in the soil (Fontanetto, 2004). Recent research with enhanced-efficiency fertilizers, including an urease inhibitor such as nBTPT, has shown improved N use efficiency (Fontanetto et al., 2010) (**Figure 6**).

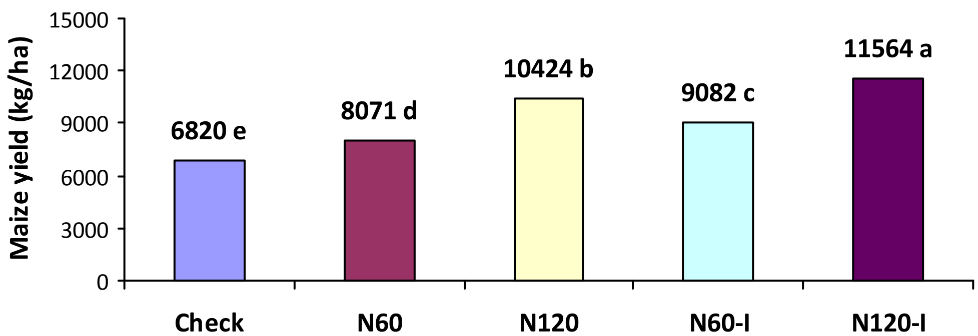

Figure 6. Grain yield for different surface-applied N rates and sources in late-planting maize at Rafaela (Santa Fe, Argentina) in the 2008/09 season (Fontanetto et al., 2010).

4. Right place

4.1. P fertilization placement for grain crops

Phosphorus fertilization for grain crops in Argentina and Uruguay, is generally carried out at planting, banding the fertilizer with or close to the seed (2-5 cm below and/or to the side), depending on planting equipment. In recent years, research has shown that pre-plant broadcast of P fertilizers would be an efficient alternative under no-tillage systems (Bordoli et al., 2004 ; Bianchini, 2003; Echeverría et al., 2004; Barbagelata et al., 2011) (**Figure 7**). This pre-plant broadcast applications should follow some considerations : i) System under no-tillage for more than 5 years, ii) Broadcast at least 45 days before planting, iii) P rates of 20 kg P/ha or more, and iv) Precipitation greater of 50 mm between application and planting.

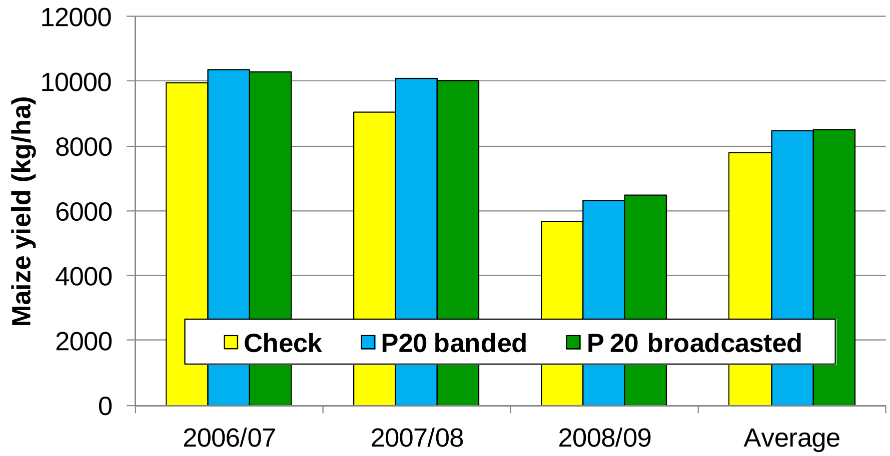

Figure 7. Maize grain yield for different P placement methods under no-tillage in three growing seasons and the average for 18 sites, at the northern pampas of Argentina. P rates are indicated as kg P/ha. Banded was done at planting, and broadcasted 45-60 days before planting. Source: G. Ferraris and coworkers, EEA INTA Pergamino, Buenos Aires, Argentina.

Final considerations

- Crop managers select practices to apply the right source at the right rate and time, and in the right place, based on decision support provided by crop advisers, extensionists, agronomists, and research scientists through on-farm, station and laboratory research.

- The 4Rs would greatly contribute in defining sustainable nutrient management in Latin America through the interaction of all stakeholders: Customers, Residents & Consumers; Advisers, Agronomists and Resource Managers; Producers; Research scientists, scientific organizations; Governments, regulatory institutions; and Fertilizer industry.

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