The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina

2. Nutrient balance, yield and grain quality

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Abstract

Wheat (\textit{Triticum aestivum} L.) in the semiarid region of Argentina has often been grown as a low-input crop. Rainfall scarcity and distribution are the main characteristics of the region. Consequently, a knowledge of the effect of different management practices is the key to sustainable crop production. The objective of this work was to study the effect of 15 years of different wheat management practices on plant nutrition, dry matter production and grain yield and quality. The treatments were: continuous wheat (WW), wheat-grazing natural grasses (WG) and wheat–legume: [vetch (\textit{Vicia sativa} L.) plus oat (\textit{Avena sativa} L.) or Triticale (\textit{Triticum aestivum} L. \times \textit{Secale cereale} L.)] (WL), with and without fertilizer (N + P) application. The WW and WL treatments involved annual tillage and a long fallow period (4–6 months) under stubble mulch, and WG involved annual alternate tillage and a short fallow (1 month). The experiment was started in 1975 and the data presented were obtained in 1989. Wheat yields were higher with the WW than with the WG rotation, but in both rotations fertilization was required to obtain better grain quality (protein content higher than 11 per cent). The wheat–legume rotation resulted in the highest yield, protein content, and better yield components. Fertilizer application did not increase dry matter production but improved nutrient uptake and grain quality. Yield component differences could be attributed to water availability due to different fallow length. The wheat–legume rotation seemed to be the best practice in the semiarid Pampean region.

Keywords: Wheat yield components; Grain quality; Crop rotation; Semiarid region; Rotation

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1. Introduction

Wheat productivity components are affected by physical, chemical and biological soil properties and climatic conditions. In semiarid regions the response to fertilizer application depends on amount and distribution of precipitation.

To improve the limited possibilities of dryland farming, it is essential to apply sustainable management practices on the land. Use of crop rotations with legumes improves soil physical (Andriulo et al., 1990a,b), chemical (Miglierina et al., 1995) and biological conditions, thereby enhancing nutrient availability and soil water contents (Loewy, 1987; Galantini et al., 1992).

Wheat yield and protein contents have been increased with N fertilization. However, increases in the rate of N application may result in greater severity of soil water deficits under dryland farming. Winter wheat grown with water stress had a shorter effective grain filling period and, consequently, lower kernel weight (Frederick and Camberato, 1995).

Plant analysis is an important tool to establish the nutritional needs of crops, but requires careful interpretation when using critical levels (Rosell et al., 1992). As plant nutrient concentrations are changing with the age of the plants, for diagnostic purpose it is better to use the nutrient ratio that remains quite constant throughout the plant cycle (Beaufils, 1973). These concepts are basic in Diagnosis and Recommendation Integrated System (DRIS) application (Sumner, 1977). The DRIS proposed by Beaufils (1973) has been used to determine the balance of N, P, K and S in wheat plants (Sumner, 1977). The DRIS procedure was used to measure deviations of actual nutrient concentration ratios in plant tissues from the values of the same ratios previously established as reference values or norms. The DRIS international norms for N, P, and K, obtained by several authors (Sumner, 1981; Beverly, 1993) have been utilized. However, some researchers have suggested that norms calculated from a local data base may improve DRIS diagnosis (Dara et al., 1992). Besides, the grain and straw analyses give complementary information on the crop nutrition and the efficiency use of the fertilizers (Martinez, 1987). Therefore, soil and plant analyses as well as crop field observations provide good information for establishing the status of the crop in the region.

The objective of this study was to evaluate the effect of 15 years of different production systems and fertilization practices on crop nutritional practices on crop nutritional balance, and on the yield and quality of wheat in the semiarid Pampean region.

2. Materials and methods

2.1. Experimental site

Field research was carried out at the INTA Agricultural Experimental Research Station, Bordenave, Province of Buenos Aires, Argentina, located in the Pampean semiarid region (63° 01′W; 37° 52′S). The experiment was started in 1975, and plant samples were taken in 1989, at the end of 15 years, when all plots were seeded with wheat. The site is representative of the central–southern semiarid Pampean region.

The climate is temperate. Mean annual rainfall and temperature are 654 mm and 15°C, respectively. The amounts of precipitation are higher in fall and spring than in winter and summer (Fig. 1). Cereal water requirements, calculated by FAO methodology (Papoloni and Vázquez, 1985), for Bordenave region are presented in Fig. 1.

The main soil sub-group is an Entic Haplustoll (FAO: Haplic Kastanozem), fine to medium sandy loam, with slope of 0–1 per cent and a caliche (calcareous) layer located at a depth between 0.8 and 1 m.

The three crop rotations studied, fully described in Miglierina et al. (1999), are:

- WW, annually cropped continuous wheat;
- WG, wheat and cattle grazing natural grasses, alternatively one year each; and
- WL, 2 years wheat and 2 years of a mixture of vetch plus oats or triticale for pasture grazed winter crops.

The WW and WL rotations had 4–6 months of fallow with residues of the previous crop with mechanical weed control and the WG had a short (1 month) fallow.

Imposed on the three rotation systems areas were non-fertilized (nf) and annually fertilized (f) treatment plots, with 64 kg N ha⁻¹ as urea and 16 kg P ha⁻¹ as diammonium phosphate applied at seeding time (June).
2.2. Plant analysis

Total aerial dry matter (TADM) was determined at stem elongation (first node visible, Feekes scale No. 6, Miller, 1992), during September, and at maturity (Feekes No. 11.4), beginning of December.

The samples were washed with distilled water, oven dried at 60°C and ground (<40 mesh). Nitrogen (N) was determined by semi-micro Kjeldahl (Bremner and Mulvaney, 1982); total phosphorus (P) and potassium (K) were obtained by the digesting samples with a perchloric–nitric acid mixture (Johnson and Ulrich, 1959) and determined by ammonium vanadate colorimetry (Murphy and Riley, 1962) and flame photometry, respectively.

Grain protein, on a 13.5 per cent kernel moisture basis, was obtained with a near infrared reflectance (NIR) system (Technicom Infraalyzer 400, Technicom Industrial Systems, USA). Gluten was determined with a Glutomatic analyzer (Perten Instruments, AB. Sweden), and the results are presented on a moist and oven-dry (105°C) basis. Sulfur determination was made with a LECO S-Analyzer (LECO Co., St. Joseph, MI, USA). Yield components such as spikes per square meter, kernels per spike and kernel weight were also obtained.

2.3. DRIS analysis

Diagnosis and recommendation integrated system (DRIS) method was applied to the determination of N, P, and K nutritional balance of the wheat at stem elongation. DRIS indices and the element sequence of the nutritional balance were obtained by using Beaufils (1973) relationships as follows:

N index = \[ \frac{f(N:P) + f(N:K)}{X} \]

P index = \[ \frac{-f(N:P) - f(K:P)}{X} \]

and

K index = \[ \frac{f(K:P) - f(N:K)}{X} \]

where \( X \) = number of functions in the numerator (in this case 2).

For the N index:

\[ f(N:P) = \left( \frac{N:P}{n:p} \right) - 1 \cdot \frac{1000}{CV} \]

when \( N > n : p \), or

\[ f(N:P) = \left( 1 - \frac{n:p}{N:P} \right) \cdot \frac{1000}{CV} \]

where \( N:P \) is the actual value of the ratio of N and P (g kg\(^{-1}\)) in the plant being diagnosed; \( n:p \) the value of the reference norm from high-yielding wheat plants and \( CV \) the coefficient of variation of this norm’s population.

The norms are utilized in empirically derived equations that result in a set of indices denoting sufficiency or deficiency of each nutrient studied. The lowest (or more negative) DRIS index indicates the most deficient or yield-limiting nutrient in comparison with the other tested elements. A DRIS index equal to zero...
means that the element is present in quantity associated with a high-yielding crop. The sum of elemental DRIS indices (NBI) equals zero; consequently, the assessment of the relative balance among diagnosed nutrients is also possible.

2.4. Data analysis

The experiment had a randomized complete block design and a split-plot arrangement with three replications. The three crop rotations were assigned to the main plots and fertilizer applied to sub-plots. Data were analyzed by the ANOVA. Tukey’s test was used to separate the mean values.

3. Results and discussion

3.1. Plant nutrient concentration and absorption

The WG rotation, with the shortest fallow period, did not increase dry matter production and nutrient absorption at stem elongation (Tables 1 and 2) as compared with the WW rotation, but stressed the crop during the grain filling stage (Table 3).

Wheat plants from the legume and fertilized rotation plots had high N contents during elongation (Table 1), but the response to fertilization was significant only for the WW rotation.

The P contents were high in plants from all treatment plots, exceeding the crop needs (Westfall et al., 1990). The WW plots had the lowest plant P content. Annual fertilization significantly increased P concentration in WW and WG, but not in WL rotation plots. Plant K concentrations were high (Westfall et al., 1990) with all treatments; however, a significant increase was observed in fertilized WL, WW and WG plots. In non-fertilized WW and WG plots, no differences were observed in early nutrient absorption (Table 1) and dry matter production (Table 2) although they had different length fallow periods.

In general, the application of N and P increased NPK uptake and TADM production. The WL rotation resulted in the largest TADM production and NPK accumulation. The effect of the legume in the WL rotation was similar to fertilizer application in WW and WG rotations (Table 2). This supports the important role of legume species as a partial substitute for fertilizers (Campbell et al., 1992).

3.2. DRIS indices and nutritional balance

A DRIS index from $-15$ to $+15$ indicates good nutrient balance in the plant (Kelling and Schulte, 1986). In all cases N was the most deficient nutrient (indices lower than $-25$), K values were around zero and P values showed an excess (more than $+25$) at stem elongation (Table 1). The high NBI indicated a

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WW nf</th>
<th>WW f</th>
<th>WG nf</th>
<th>WG f</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>30.3  c</td>
<td>34.3 ab</td>
<td>32.7  b</td>
<td>34.5 ab</td>
<td>34.2 ab</td>
<td>35.6 a</td>
</tr>
<tr>
<td>P</td>
<td>3.1   c</td>
<td>3.5  b</td>
<td>3.5   b</td>
<td>3.9  a</td>
<td>3.4 bc</td>
<td>3.6 ab</td>
</tr>
<tr>
<td>K</td>
<td>42.6  c</td>
<td>52.5 ab</td>
<td>42.0  c</td>
<td>49.8 b</td>
<td>51.1 b</td>
<td>57.3 a</td>
</tr>
<tr>
<td>DRIS index</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>97</td>
<td>98</td>
<td>93</td>
<td>103</td>
<td>93</td>
<td>99</td>
</tr>
<tr>
<td>P</td>
<td>97</td>
<td>90</td>
<td>106</td>
<td>107</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>K</td>
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<td>8</td>
<td>13</td>
<td>4</td>
<td>7</td>
<td>13</td>
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<tr>
<td>NBI</td>
<td>194</td>
<td>196</td>
<td>212</td>
<td>214</td>
<td>186</td>
<td>198</td>
</tr>
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</table>

$^a$ WW: continuous wheat; WG: 1 year wheat – 1 year grazing natural grasses; WL: 2 years wheat – 2 years legume and grass mixture; nf: non-fertilized and f: fertilized. Different letters in a row indicate significant differences between treatments ($p < 0.05$, Tukey’s test).
nutritional imbalance with all treatments, regardless of fertilizer application and crop rotation.

3.3. Yield components

The spike number per unit area was greatest for wheat on WL rotation plots, and similar on WW and WG plots (Table 4). The number of spikelets per spike were similar with all treatments. Only the differences between the numbers for the WWf, WGnf and WLnf treatments were significant. When water became limiting, the large spike number for the WWf treatment resulted in small spikelets (Evans and Wardlaw, 1976).

The weight of kernels was similar with all treatments, except that the WWnf treatment resulted in a higher value due to the low number of kernels per square meter.

Fertilization increased plant height in the WW and WG rotation plots, but no response was found in the WL rotation plots due to their inherent fertility (Table 4).

The close relationship between yield components and rainfall distribution is well known. Water availability, accumulated during the fallow period and rainfall, was higher than plant needs during the early stage of growth (Fig. 1). For this reason the increased number of spikes per square meter can be attributed to the fertilizer application or crop rotation. Later on, when water became a limiting factor, differences in the number of spikelets per spike were observed.

Table 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>WW</th>
<th>WG</th>
<th>WL</th>
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<tbody>
<tr>
<td>TADM</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>nf</td>
<td>1140 c 1960 ab</td>
<td>1230 c 1960 b</td>
<td>1930 ab 2440 a</td>
</tr>
<tr>
<td>f</td>
<td>1960 c 1230 b</td>
<td>2440 a 1930</td>
<td>1930 ab 2440 a</td>
</tr>
<tr>
<td>N</td>
<td>33.4 c 67.3 b</td>
<td>40.2 c 67.1 b</td>
<td>65.9 b 86.7 a</td>
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<tr>
<td>P</td>
<td>3.6 c 6.9 b</td>
<td>4.3 c 7.6 b</td>
<td>6.5 b 8.9 a</td>
</tr>
<tr>
<td>K</td>
<td>49.2 c 103.1 b</td>
<td>51.6 c 97.3 b</td>
<td>98.4 b 139.3 a</td>
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Table 3

<table>
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<th>WL</th>
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</thead>
<tbody>
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<td></td>
<td></td>
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<tr>
<td>nf</td>
<td>2920 c 3580 b</td>
<td>2190 d 3060 c</td>
<td>4110 a 4050 a</td>
</tr>
<tr>
<td>f</td>
<td>3580 b 2190 d</td>
<td>3060 c 4110 a</td>
<td>4050 a 4110 a</td>
</tr>
<tr>
<td>Straw</td>
<td>6260 cd 7340 bc</td>
<td>4990 d 6290 cd</td>
<td>8510 a 8910 a</td>
</tr>
<tr>
<td>Total dry matter</td>
<td>9180 c 10920 bc</td>
<td>7180 d 9340 c</td>
<td>12620 ab 12960 a</td>
</tr>
<tr>
<td>Protein</td>
<td>290 cd 420 b</td>
<td>240 d 360 bc</td>
<td>520 a 560 a</td>
</tr>
</tbody>
</table>

Table 4

<table>
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<th>Parameters</th>
<th>WW</th>
<th>WG</th>
<th>WL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spike (m⁻²)</td>
<td>242 c 445 ab</td>
<td>230 c 379 b</td>
<td>429 ab 472 a</td>
</tr>
<tr>
<td>Kernel (spike⁻¹)</td>
<td>19.9 ab 18.6 b</td>
<td>20.6 a 19.9 ab</td>
<td>20.0 ab 19.7 ab</td>
</tr>
<tr>
<td>Kernel weight (mg kernel⁻¹)</td>
<td>37.6 a 35.6 ab</td>
<td>35.0 b 33.8 b</td>
<td>34.0 b 34.9 b</td>
</tr>
<tr>
<td>Plant height (cm)</td>
<td>84.5 c 104.0 a</td>
<td>78.8 c 94.2 b</td>
<td>103.2 a 102.9 a</td>
</tr>
</tbody>
</table>

a The column headings have the same meaning as in Table 1.
Grain filling and TADM production were affected by water stress.

3.4. Plant productivity

The WL rotation resulted in the highest grain, straw, and protein yields (Table 3). For the WW and WG rotations straw and protein production were similar but lower than for WL, and their grain yields were 2920, 2190 and 4110 kg ha\textsuperscript{-1}, respectively. This may be attributed to the high fertility, mainly P and water availability (Miglierina et al., 1999), generated by the different fallow length.

Fertilization produced a wheat yield increase in WW and WG but not in the WL plots. Grain yields with the WL rotation were high compared with the average for the region (ca. 1200 kg h\textsuperscript{-1}). Wheat water deficits during the reproductive stages (October–November) (Fig. 1) are usually observed in this semiarid region, which impair nutrient uptake and fertilizer response. Previously, it had been observed that the incorporation of legumes in the crop rotation improved wheat yield and quality (Galantini et al., 1992) but, under low rainfall, such practice may be detrimental to grain production (Loewy, 1987).

With the non-fertilized treatments, wheat N uptake was higher in WL than in WW and WG rotation plots (Table 5). The long fallow period with WW did not increase the N harvested with respect to WG.

Fertilization only increased plant N in rotations without legume, due to higher grain N content (Table 5). Other authors (e.g., Martinez, 1987) found similar results, the fertilization of continuous wheat resulted in a higher N recovery, grain yield and protein content than the WGf treatment (Table 3). Rainfall timing and amount were important factors for the growth of wheat (Sanchez de la Puente and Belda, 1992).

The WW rotation resulted in similar soil porosity distribution and higher soil N content but it did not show a response to fertilizer application with respect to the WG rotation. This behavior may be attributed to the short fallow period used with this treatment. These results, as previously reported (Galantini et al., 1992), showed that fertilizer application can be partially replaced by legume crops in wheat rotations.

The highest straw N content occurred with the WL rotation. When left on the field it will be incorporated into the labile organic matter fraction and recycled, reducing the N needs in the following crop (López-Bellido et al., 1996).

Protein contents in grain were lower than 11 per cent with the WW and WG non-fertilized rotations, and these were significantly lower than in WL plots (Table 6). Other authors (e.g., Campbell et al., 1992) found that non-fertilized continuous wheat produced low protein content grain. Previous studies in the Pampean semiarid region (Galantini et al., 1992) showed that it was necessary to apply N fertilizers to maintain protein contents of 11 per cent or higher. Complementary information about grain quality can be obtained from gluten contents and N:S ratios since the gluten and protein contents are closely related. When N:S ratios are greater than 17 and grain S concentrations are lower than 1 g kg\textsuperscript{-1} a response to fertilizer application is expected (Withers et al.,

| Table 5 |

<table>
<thead>
<tr>
<th>Parameters</th>
<th>WW</th>
<th>WG</th>
<th>WL</th>
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</thead>
<tbody>
<tr>
<td>Grain</td>
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<td></td>
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<tr>
<td>Concentration</td>
<td>20.5 d</td>
<td>22.1 cd</td>
<td>23.9 bc</td>
</tr>
<tr>
<td>Yield</td>
<td>59.9 cd</td>
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<td>73.2 bc</td>
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<tr>
<td>Straw</td>
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<td></td>
</tr>
<tr>
<td>Concentration</td>
<td>2.30 c</td>
<td>2.94 bc</td>
<td>3.24 ab</td>
</tr>
<tr>
<td>Yield</td>
<td>14.5 c</td>
<td>14.2 c</td>
<td>18.3 c</td>
</tr>
<tr>
<td>Total above ground dry matter</td>
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<tr>
<td>Yield</td>
<td>74.4 cd</td>
<td>62.5 d</td>
<td>91.5 bc</td>
</tr>
</tbody>
</table>

* The column headings have the same meaning as in Table 1.
An N:S ratio of 13 or lower indicated adequate S contents (Table 6).

### 4. Conclusions

This study shows the effects of 15 years of wheat rotations with data confined to only one year (1989). In this context, the wheat–legume rotation resulted in higher yields and protein contents, and better yield components than the other two rotations (WW and WG). Fertilizer applications improved grain protein and N straw content, but had little effect on yield in WL plots. The WW and WG rotations resulted in intermediate and the lowest yield components, respectively. Crops required N fertilizer applications to achieve acceptable grain production and protein contents.

The treatment involving wheat and annual legumes (WL) did not require fertilizer applications to achieve the potential crop yields of the semiarid Pampean region and this rotation is considered to be the more ecological and sustainable system for the low rainfall farms of this region. However, in view of the dominant effect of seasonal weather, especially rainfall, on crop responses to rotation and fertilization, the results of this study must be interpreted with caution.

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