Yield and arbuscular mycorrhiza of winter rye in a 40-year fertilisation trial

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Abstract – The impact of different fertilisation treatments on soil organic matter, available soil nutrients, mycorrhizal and root properties, as well as on the yield response of winter rye (Secale cereale) was studied in a long-term field trial in Austria under dry site conditions. Winter rye has been grown since 1906 in soils treated with easily soluble mineral fertiliser, farmyard manure, and in an unfertilised control. We found the soil organic matter to be 96% higher in the plots fertilised with farmyard manure compared with easily soluble mineral fertiliser. Available soil phosphorous and potassium contents were at least 136% higher in both fertilised treatments than in the unfertilised control. Arbuscular mycorrhizal colonisation (+46%) of winter rye roots by indigenous arbuscular mycorrhizal fungi, arbuscule frequency (+20%), and the length of the extraradical arbuscular mycorrhizal mycelium (+18%) were higher in the unfertilised control and reduced in the NPK treatment compared with the farmyard manure treatment. The average grain yield of winter rye from 1960 to 2000 increased in all treatments. This increase was higher in the fertilised treatments, +41% for farmyard manure and +60% for easily soluble mineral fertiliser, than in the unfertilised control. Two main effects presumably accounted for the continuously increasing average winter rye yield in all fertilisation treatments: (1) the use of modern winter rye varieties with a higher nutrient efficiency; and (2) an ongoing atmospheric nitrogen deposition. We conclude that the preferential application of farmyard manure, typical for low-input farming systems, resulted in increased levels of soil organic matter, arbuscular mycorrhizal colonisation and arbuscule frequency, supporting soil fertility by an enhanced crop nutrient uptake by arbuscular mycorrhizal fungi under dry site conditions, thus promoting crop yield stability and sustainable plant growth.

1. INTRODUCTION

Recent adverse environmental effects of high-input agricultural systems, e.g. pollution of groundwater due to the application of easily soluble mineral fertilisers, have increased the public interest in sustainable agricultural systems such as organic farming, where soluble mineral fertilisers are prohibited (Oberson and Frossard, 2005). Symbioses of crop plants with soil micro-organisms are crucial for soil fertility and crop nutrition in low-input farming systems. The effects of low-input management practices such as organic manuring on soil microbial communities need to be understood to increase soil fertility for sustainable crop production (Mäder et al., 2002).

Applying farm yard manure (FYM) has a long-term effect on physical soil properties and soil micro-organisms (Mäder et al., 1995). It usually takes several decades until a dynamic equilibrium in the content and quality of soil organic matter has been reached (Reganold et al., 1987). Therefore, long-term field trials are required to assess the sustainability of organic matter-based management practices on crop yield and soil fertility. Only a few results, however, are available about soil nutrient contents, arbuscular mycorrhizae and crop yield from long-term fertilisation field trials.

In dry soils, the mobility of nutrients in soil solution and the microbial activity that mobilises mineral nutrients from the solid phase are generally reduced. Under such dry conditions, the nutrient availability to crops may be insufficient, especially in low-input agricultural systems.

An arbuscular mycorrhiza is a symbiotic relationship between arbuscular mycorrhizal fungi and plant roots (Smith and Read, 1997). Most crop plants in temperate agricultural systems build an arbuscular mycorrhiza; therefore, arbuscular
mycorrhizal fungi play a key role in nutrition, water relations, and in resistance against plant pathogens and diseases of crop plants (Jeffries et al., 2003), particularly in organic farming (Gosling et al., 2006). Furthermore, arbuscular mycorrhizal fungi can improve plant growth, especially in dry soils (Augé, 2001). Agronomic practices such as fertiliser application, tillage or crop rotation have major effects on arbuscular mycorrhizal fungi communities (Galvez et al., 2001; Oehl et al., 2003). Applying organic fertilisers such as farmyard manure can enhance the arbuscular mycorrhizal diversity and colonisation of host plants compared with inorganic fertilisers (Allen et al., 2001; Oehl et al., 2004). Little is known, however, about long-term effects of different fertilisation treatments on arbuscular mycorrhizal colonisation of crops under dry site conditions.

Our study therefore evaluates the effects of easily soluble mineral fertilisers, farmyard manure and an unfertilised control on soil nutrient content and on the relation between arbuscular mycorrhizal colonisation with indigenous arbuscular mycorrhizal fungi and the yield of winter rye (Secale cereale). The approach involves a long-term field trial under dry site conditions.

2. MATERIALS AND METHODS

2.1. Study site

The study was performed in a long-term field trial conducted by the Department of Applied Plant Sciences and Plant Biotechnology on the experimental Farm of the University of Natural Resources and Applied Life Sciences of Vienna in Gross-Enzersdorf, Austria, in the year 2000. The long-term field trial is located north-east of Vienna (48°11′N, 16°33′E) in the so-called “Marchfeld”, an area with about 100 000 hectares of farmland at an altitude of 150–160 m above sea level. The soil on the study site is a Calcaric Phaeozem from Loess and alluvial fine sediment with a silty loam texture (25% clay, 64% silt, 11% sand) and a pH (CaCl2) of 7.6. The climate in the Marchfeld is pannonic, characterised by hot, dry summers with little dew, and cold winters with little snow. The long-term average (1971–2000) annual precipitation is 520 mm; the mean annual temperature is 9.8 °C. In the cropping season 1999–2000, the total precipitation amounted to only 501 mm, whereas the annual mean temperature (11.2 °C) was well above the average.

2.2. Experimental design and management

The long-term field trial was started in 1906 to test the possibility of completely replacing farmyard manure by easily soluble mineral fertilisers, and whether different fertilisation systems can compensate for crop rotation deficits from continuous cropping of winter rye (Steineck and Ruckenbauer, 1976).

The field trial comprised an area of 4000 m², which is divided into four long plots of 1000 m², each with three equal sub-plots (20 m × 13 m), and split into two parts (Fig. 1).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N (kg ha⁻¹ a⁻¹)</th>
<th>P (kg ha⁻¹ a⁻¹)</th>
<th>K (kg ha⁻¹ a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NPK</td>
<td>117</td>
<td>44</td>
<td>125</td>
</tr>
<tr>
<td>FYM</td>
<td>117</td>
<td>44</td>
<td>125</td>
</tr>
</tbody>
</table>

In the first three neighbouring plots, an old crop rotation (bare fallow – winter rye – spring barley) has been performed since 1906, whereas continuous rye cropping has been carried out on the fourth plot (grey shaded). Each plot was divided into 3 sub-plots, one not fertilised at all (control). The second plot was exclusively treated with easily soluble mineral fertiliser (NPK), i.e. Nitramoncal (27% water-soluble nitrogen as nitrate and ammonium), superphosphate (16% water-soluble phosphorous as P2O5) and potassium chloride granulate (60% water-soluble K2O). The remaining, third plot was treated only with farmyard manure (FYM). The plots with bare fallow were not fertilised. The average annual fertilisation rate was the same in the farmyard manure and easily soluble mineral fertiliser treatments (Tab. I).

The plots in the cropping season of the experiment were sown with the Austrian rye variety “Tschermak’s veredelter Marchfelder” at a rate of 500 kernels m⁻², equivalent to 175 kg ha⁻¹. The straw was completely removed from the plots after the harvest every year.

2.3. Soil and root sampling and analysis

Four sub-samples consisting of 5 soil cores at 2 soil depths (3 cm diameter, sampling depth 0–10 and 10–30 cm) were taken from each sub-plot at shooting of the rye plants in early