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Yield and disease control in winter wheat in southern Sweden during 1977–2005

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ABSTRACT

Fungicides are routinely used to prevent yield losses in winter wheat in southern Sweden. Yield and 1000 grain weight (TGW) data from 432 trials in farmers' fields were evaluated to review long-term yields (1977–2005) and control of eyespot and Leaf Blotch Diseases (LBDs, including Septoria tritici blotch, Stagonospora nodorum blotch and tan spot), powdery mildew, brown rust and yellow rust. Regression analyses revealed that control of LBDs explained 74% of the yield increase achieved by fungicide treatment at GS 45–61, followed by powdery mildew (20%), brown rust (5%) and yellow rust (1%). Yield of both untreated and fungicide-treated plots increased from approx. 6000 to 12 000 kg ha^{-1} over the period 1983–2005. Single eyespot treatment improved yield by ~320 kg ha^{-1} yr^{-1} during the period 1977–2002, mainly due to occasional years with severe eyespot. Single leaf disease treatment at GS 45–61 increased mean yield by 10.3% or 810 kg ha^{-1} yr^{-1} (9.9% or 660 kg ha^{-1} yr^{-1} for 1983–1994 and 10.7% or 970 kg ha^{-1} yr^{-1} for 1995–2005) due to increased TGW and grain numbers, especially in high-yielding stands. Additional extra early treatment at GS 30–40 against LBDs increased yield by ~250 kg ha^{-1} yr^{-1}. Estimated variance in yield and TGW was higher between years than within years, while that in yield increase and plant diseases was lower between years than within. The results confirm potential and limits of fungicides and the need for supervised control strategies including factors affecting disease, yield and interactions.

1. Introduction

Since 1980, the total area of arable land in southern Sweden has been decreasing, but the mean acreage of winter wheat has increased from 50 000 ha to 90 000 ha, representing more than 25% of the total winter wheat acreage in Sweden (SCB, 1983–2006).

Leaf blotch diseases (LBDs) on winter wheat caused by *Mycosphaerella graminicola* (anamorph *Septoria tritici*), *Pyrenophora tritici-repentis* (anamorph *Drechslera tritici-repentis*) and *Phaeosphaeria nodorum* (anamorph *Stagonospora nodorum*), are the most serious cereal pathogens in Sweden (Wiik et al., 1995; SJV, 2008). Other diseases such as powdery mildew (*Blumeria graminis*), brown rust (*Puccinia triticina*) and yellow rust (*Puccinia striiformis*) also contribute to yield losses due to the destruction of green leaf area, in particular on the two top leaves (Shaw and Royle, 1989a) and ears. Eyespot caused by the sibling fungal species *Oculimacula acuformis* and *Oculimacula yallundae* (earlier described as one fungus with the anamorph *Pseudocercosporella herpotrichoides*), is important and sometimes requires fungicide treatment (SJV, 2008).

As in other countries, results from field trials have been used in Sweden to give recommendations on fungicide products, timing and dosages (e.g. Cook and Thomas, 1990). In recent decades, a fungicide treatment against LBDs just before/during heading [growth stage (GS) 47–55 according to Tottman, 1987] has been profitable in most years and is now routine for many farmers in southern Sweden (SJV, 2008). When tan spot caused by *D. tritici-repentis* is a problem, a split application at GS 37–39 and GS 55–59 is recommended. However, in years when LBDs are inhibited due to dry conditions, the use of fungicides has been questioned (Wiik, 1993). For many diseases such as the LBDs, eyespot, powdery mildew and rusts, the use of threshold values or warning forecasts aid decisions regarding treatment. Winter wheat diseases, treatments and yield levels have been regularly studied in field trials and reviewed (e.g. Andersson et al., 1986 and Wiik et al., 1995). However, there are few scientific studies of the impact and dynamics of diseases on yield and yield loss over longer periods of time.

This study evaluates the results from field trials 1977–2005 for eyespot and, 1983–2005 for leaf diseases. The objectives were to examine the relationships between fungicide treatments and yield and multiple diseases and yield, and to determine variations in yields and diseases within and between years.

2. Materials and methods

Data were obtained from 432 trials in winter wheat fields on farms in southern Sweden (55°23′–56°25′N, 12°50′–14°31′E) in the

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period 1977–2005. The trials investigated different treatment strategies and fungicides applied at GS 30–61 in different cultivars and at different nitrogen levels and were carried out by staff at the Rural Economy and Agricultural Societies.

2.1. Cultural practices in commercial fields and cultivars

In general, sowing, fertilisation, weed and insect pest control were performed by farmers, the field trials included. The field trials were predominantly situated on good agricultural soils with a mean content of 17% clay and 3.3% organic matter and an adequate supply of phosphorus and potassium. Mean sowing date for winter wheat was 18 September (range 11 September–3 October) and mean harvest date was 23 August (range 5 August–25 September). The period from sowing to harvest was 340 days (range 314–375 days). Mean mineral nitrogen (N) applied during the period was 155 kg N ha^{-1} and mean total N including estimated available soil N from the preceding crop and from manure was 177 kg N ha^{-1}. The preceding crop was oilseed rape (54%), cereals other than wheat (17%), leguminous plants (9%), wheat (7%) and other crops (13%). The most common cultivars in the field trials during 1977–1982 were Solid (49%), Holme (20%), Helge (17%), Folke (7%), Hildur (5%) and Walde (2%) and in the field trials during 1983–2005 Kosack (33%), Folke (13%), Ritmo (10%) and Kris (7%). The cultivars Holme, Kraka, Konsul, Meridien, Bercy, Bill and Marshal represented 2–3% respectively, while another 17 cultivars represented less than 2% each. Folke predominated during 1983–1986, while Kosack was used in over 60% of trials during 1987–1994. Ritmo predominated during 1995–2000 and Kris during 2001–2005. Field trials during 1977–1994 used 2–4 cultivars per year, while field trials 1995–2005 used 5–8 cultivars.

2.2. Field trial design

The trials were randomised in a block design with four replicates. The number of treatments per trial differed during the period but each usually included about 10 treatments and an untreated control. Plot size was usually 4 × 12 m and harvested area (excluding border rows) was 2 m × 10 m, i.e. 20 m^2 per plot.

2.3. Fungicides and fungicide treatments

Different types of fungicides and fungicide combinations containing active ingredients such as benzimidazoles, aromatics, morpholines, azoles, amides, strobilurins and pyrimidines were used in the field trials. Standard products at recommended dosages were generally used, e.g. 0.5 L ha^{-1} Tilt 250 EC, a.i. propiconazole 250 g L^{-1}; 0.8–1.0 L ha^{-1} Tilt Top 500 EC, a.i. propiconazole 125 g L^{-1} + fenpropimorph 375 g L^{-1}; 0.5–1.0 L ha^{-1} Amistar, a.i. azoxystrobin 250 g L^{-1}. Calibrated field crop sprayers with fan nozzles at a pressure of 300 KPa pressure and 200 L water ha^{-1} were used as described in standard operating procedures of the Swedish GEP system.

Growth stages (GS) according to Tottman (1987) were used: Stem elongation [ear at 1 cm (pseudostem erect) (GS 30) to flag leaf ligule just visible (GS 39)]; booting [flag leaf sheath extending (GS 40) to first awns visible (GS 49)]; inflorescence (ear/panicle) emergence [first spikelet of inflorescence just visible (GS 50) to emergence of inflorescence completed (GS 59)]; anthesis (flowering) [beginning of anthesis (GS 60) to anthesis complete (GS 69)]; milk development [caryopsis (kernel) water ripe (GS 70) to late milk (GS 79)].

In addition to an untreated control, one or more of the following four treatments were included in trials: 1) A single early treatment at GS 30–33 (mean GS 31 May 17) with fungicides effective primarily against eyespot, 1977–2002; 2) a single treatment with fungicides against LBDs, mildew, yellow rust and brown rust just before/during heading at GS 45–61 (mean GS 53 June 14), 1983–2005; 3) a split treatment with fungicides against leaf diseases including an early treatment at GS 31–40 followed by one at GS 45–61 and 4) a split treatment with an early treatment at GS 30–33 primarily against eyespot, followed by a treatment at GS 45–61 with fungicides against leaf diseases. In early years, eyespot was primarily treated with benzimidazoles and LBDs with azoles, but also amides and a conazole–morpholine mixture. In later years, pyrimidines were generally used against eyespot and strobilurins, conazoles and morpholines against leaf diseases, often in different combinations.

2.4. Disease assessment

The severity of leaf diseases on the top leaves was usually assessed before treatment and 3–5 weeks after last treatment (EPPO Standards PP1, 2004) as percentage damage to flag leaf or top leaf, leaf 2 or the leaf below the flag leaf, leaf 3 or the leaf below leaf 2 and leaf 4 or the leaf below leaf 3. The necrotrophic LBDs caused by *S. tritici*, *St. nodorum* and *D. tritici-repentis* were assessed as one disease due to mixed symptoms. If needed, disease severity at GS 55 on leaf 3 and GS 75 on leaf 2 was estimated by additional assessments. The formula $y = 0.42 \times xii$ [y = grain yield loss (%) and xii = disease (%) on leaf 2 (flag-1) in the range 0–45%] (Thomas et al., 1989; Cook et al., 1991) was used to estimate yield loss caused by LBDs. Fungicide efficacy was calculated as reduction in LBD-infected leaf area (%) in treated plots compared with untreated. An eyespot index was calculated from assessments on samples taken during GS 65–77 as (% weakly attacked tillers)/4 + (% moderately attacked tillers)/2 + (% severely attacked tillers)/1, modified from Scott and Hollins (1974).

2.5. Yield

The field trials were harvested with plot combines, mostly Hege and Sampo. Samples of 1 kg from each treatment were analysed for water content and 1000 grain weight (TGW). Yield and TGW were reported at 15% water content and grains m^{-2} were estimated from yield and TGW. Degree of lodging (0–100, 0 = upright stand and 100 = totally lodging) was graded just before harvest.

Actual yield responses due to a fungicide treatment at GS 45–61 for five disjunctive disease severities were studied at high and low yield levels (high yield level >9250 kg ha^{-1} and low yield level <9250 kg ha^{-1} based on yields for fungicide treatment at GS 45–61; and high yield level >8250 kg ha^{-1} and low yield level <8250 kg ha^{-1} based on yields in untreated plots).

2.6. Statistical methods

Pearson correlation, ANOVA, regression and variance component were analysed using SPSS (ver. 13.0) (Hawkins, 2005). The Student–Newman–Keuls procedure with multiple range tests was used to compare means. Variance component analyses (Restricted Maximum Likelihood Estimation, REML) were used with year as random factor [GLM, var(year) and var(error)] to differentiate effects within and between years for different variables.

3. Results

3.1. Yield

Yields of both untreated and fungicide-treated winter wheat increased during the period 1983–2005 from ∼6000 to 12 000 kg ha^{-1} (Fig. 1). Mean yield was 8640 kg ha^{-1} in treated field trials and 7830 kg ha^{-1} in untreated. The annual increase in yield