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Weather related risks in Belgian arable agriculture

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ABSTRACT

Agricultural production risk is to a great extent determined by weather conditions. The research hypothesis was that adverse weather conditions during sensitive crop stages do not entirely explain low arable yields. The temporal overlap between weather conditions and crop stages in the arable cropping system was determined using a modelling framework that couples phenology to the soil water balance and crop growth. While climatic constraints have changed on average over time, block maxima of indicators during crop growth stages showed no trends, except for minimum temperature related indicators, owing to a dual shift in both phenology and weather conditions. Return periods were derived for adverse weather conditions such as frost, drought, heat and waterlogging, and for general weather conditions such as radiation, temperature, precipitation and the water balance using fitted statistical distributions for the period 1947–2012. Distributions fitted to detrended yields allowed relating weather conditions during the growing season to the lower and upper quintiles of the yield distributions. Weather conditions varied significantly between years, crops and growth stages. Results for winter wheat, winter barley, winter oilseed rape, grain maize, potato and sugar beet in Belgium demonstrated that the impact of single events on crop yields was difficult to capture, as yields integrated weather variability during the growing season and crops recovered from adverse weather conditions. The approach of combining physically based crop modelling with statistical distribution fitting to characterise the tail ends within the range of observations of both crop yields and weather conditions showed that water (drought and waterlogging) and temperature (frost and heat) stress resulted in low arable yields when they occurred either in concatenation or in combination with adverse weather conditions such as low radiation during the growing season. The method helped quantify agricultural production risks and rate both weather and crop-based agricultural insurance.

1. Introduction

Agricultural production is to a great extent determined by weather conditions. Managing weather related risks includes both on-farm measures and strategies to share the risk such as insurance schemes. Weather related risks are projected to increase in magnitude, frequency and duration under climate change (Field, 2012; WMO, 2011; Solomon et al., 2007). The perspective of this rising risk-exposure is exacerbated further by an overall reduction of direct income support from the CAP and more limits to aid received for crop damage (Council Regulation 73/2009, Commission Regulation 1857/2006). The condition that farmers can claim only 50% of the estimated damage if they are not privately insured against weather risks has triggered renewed interest in private agricultural insurances.

Agricultural insurance schemes across Europe range from single and combined to yield risk insurances, and depend largely upon the degree of government subsidies (Bielza Diaz-Caneja et al., 2009). In response to high risk and damage (Punge and Kunz, 2016), single risk insurance for hail is the most developed private insurance product available in all European countries (Mauelshagen, 2011), but there is gathering interest to include other meteorological triggers such as drought and frost, and offer a more comprehensive weather-based insurance cover. In general combined risk insurances are offered in regions with higher or multiple risks due to hail, rain, frost and wind (Bielza Diaz-Caneja et al., 2009). Combined risk insurance ranges from public and compulsory in Greece and Cyprus; private and partially subsidised in Portugal, Czech Republic, Slovakia, and Romania; to completely private in the Baltic States, Hungary and Bulgaria. Yield insurances guarantee the main risks affecting production, include systemic risks such as drought, and are available in a private partially subsidised system in Spain, Italy, Austria and France (Enjolras et al., 2012). In all European countries compensation for yield losses due to natural disasters is offered by public disaster funds; is subject to which risk caused the loss, the area affected and the magnitude of damage; and, invokes a clear trade-off between providing catastrophic assistance and subsidising insurance premiums (van Asseldonk et al., 2013). In 2006 the total agricultural insurance premiums in EU-25 was 1538 M€, with 32% subsidised by Member States (Bielza Diaz-Caneja et al., 2009). In comparison, the

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2012 drought resulted in a $11.581 billion payment to U.S. farmers (Wilson, 2013). The crop insurance market is less mature in Europe than in the U.S. or Canada, where whole-farm income insurance and area yield or area revenue insurances exist. Knowledge gaps relate to the frequency and magnitude of adverse weather conditions and the resulting crop response.

Extreme weather events are meteorological phenomena that are at the extremes of the historical distribution, whereas severe weather refers to any dangerous meteorological phenomena with the potential to cause damage (WMO, 2011). Examples of extreme weather events include heat waves, droughts, storms and floods. Strong winds, hail, excessive precipitation, late spring frost and lightning (causing wildfires) are forms of severe weather. Extreme value theory provides a statistical framework to make inferences about the probability of extreme events beyond what has been observed (Coles, 2001; Beirlant et al., 2004; Dey and Yan, 2016). Insurance companies and disaster funds in Europe define extreme weather events in relation to agricultural damage as events equalling or exceeding a 20-year return value; a definition that points to adverse weather events from a meteorological point of view. Adverse weather events happen once or more in a lifetime, have lower return periods and have higher frequencies of occurrence during the observation interval as compared to extreme events. Following normality testing or transformation to normality, the cumulative frequency of adverse weather events may be approximated by the standard normal cumulative distribution function.

The degree of temporal overlap between adverse weather conditions and crop development leads to different crop performance responses. A significant advancement in crop phenology provides important evidence of the response to recent regional climate change (e.g. in Germany by Estrella et al., 2007), and ultimately influences crop yield. For example, during the 2003 heat wave a reduction of 30% was estimated in gross primary production of terrestrial ecosystems over Europe (Ciais et al., 2005), but winter cereal yields in Belgium and northern France were normal because wheat matured earlier thereby avoiding severe losses from drought and heat stress (Gobin, 2010; Peltonen-Sainio et al., 2010). Warming during spring and early summer accelerates canopy development and increases sugar beet yield (Jaggard et al., 2007). Evidence of negative impacts of advancing phenology is that premature plant development can result in exposure of vulnerable plant tissues and organs to for example late-season frosts (e.g. in US by Gu et al., 2008). Changes in planting date, emergence and seedling establishment could therefore cause positive or negative yield changes. Farmers' sowing dates, however, were found not to have changed significantly under the warmer growing conditions of the last decades (Van Oort et al., 2012b; Jaggard et al., 2007). The impacts of adverse weather on crop yields necessitates a modelling approach that takes into account the progression of growth stages in the cropping calendar such that the occurrence of sensitive periods can be identified and related to adverse weather conditions.

Time windows considered for studying adverse weather impacts on crops range from the entire growing season to a few days around sensitive phenological stages such as flowering. Monthly to three-monthly temperature and precipitation anomalies during the growing season were found to relate significantly to crop yields of barley, wheat and maize, e.g. in the Czech Republic (Kolář et al., 2014) and in France (Ceglar et al., 2016). Sugar beet is susceptible to drought during foliage expansion (Richter et al., 2001) and wheat to hot temperatures around the flowering period (Wheeler et al., 2000). Based on these findings, crop modelling predicts that under future climate change, an increase in the frequency and magnitude of heat stress around the time of flowering, not drought, will increase the vulnerability of heat-sensitive wheat varieties in Europe (Semenov and Shewry, 2011). For grain maize, heat stress was found to reduce grain yield due to a decline in harvest Index induced by above optimal temperatures around flowering (Edreira and Otegui, 2012). The exceedance of critical thresholds during the growing season can result in crop damage as reviewed for temperature thresholds during different phenological phases and physiological processes of winter wheat (Porter and Gawith, 1999) and grain maize (Sánchez et al., 2014). A comprehensive review of weather conditions or events during different stages of the growing season and the relationship with arable crop yields is a prerequisite to understanding risks in agricultural production.

In Belgium weather-related events recorded in the last decades have captured the interest of the general public. In August 2003, record breaking temperatures exceeded 40 °C in Belgium. Prolonged drought hit the 2007, 2010, 2011 and 2015 spring seasons causing crop damage. In May 2009 and June 2014, storms with lightning and hail resulted in crop damages across the country. In November 2010, excessive rainfall of up to 90 mm during 3 days triggered the worst flooding in 50 years. Based on claims to the disaster fund, the most important impacts on agriculture are from temperature (heat waves, frosts), precipitation (drought, waterlogging) and storms (wind, hail, flooding). Although most crops are vulnerable to hail, meteorological measurements are not readily available. Communications with the insurance and agriculture sectors revealed the need for analysing meteorological risks that impact crop yields to explore the feasibility of single risk, combined risk or index-based crop insurances. The research hypothesis is that adverse weather events during sensitive crop stages do not entirely explain low arable yields. The major objectives are to characterise adverse weather conditions; evaluate their occurrence during the cropping calendar and in particular in relation to sensitive crop stages; characterise low arable yields in terms of their distribution; and, relate adverse weather conditions to low arable yields.

2. Materials and methods

2.1. Literature review of sensitive crop stages

The focus was on identifying the most sensitive stages of the major arable crops that occur in Belgium: winter wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.), sugar beet (*Beta vulgaris* L.), late potato (*Solanum tuberosum* L.), grain maize (*Zea mays* L.) and winter oilseed rape (*Brassica napus* L.). A literature review of arable crop vulnerability to adverse weather conditions and events during different phenological stages showed that crop establishment, the transition from vegetative to reproductive growth (flowering time) and harvest were the most sensitive crop stages (Table 1). Where possible relevant thresholds were provided for the different crop stages, and their impact on yield was documented (Table 1). The crop stages with a large impact on yields were related to the cropping calendar in Belgium and included leaf development; mid-season stages around flowering, grain filling and tuber setting; and, harvest (Fig. 1).

2.2. Assessment of the growing season and crop phenology of arable crops

Most arable crops are susceptible to adverse weather conditions during the entire length of the growing season. Inter-annual variability in potential growing season length was evaluated in potential heat units (ΣPHU in °C.days) using fixed planting and harvesting dates and crop specific upper and lower threshold temperatures (Table 2). The inter-annual variability of crop phenological development necessitated the use of a crop growth model, *in casu* REGCROP (Gobin, 2012), to capture the dynamics of growth between the different years. The onset of crop phenological stages was controlled by thermal time (*cGDD*) using annual median planting dates and crop specific upper and lower threshold temperatures (Table 2; Gobin, 2010), and further refined with day-length and vernalisation responses to reflect winter crop development.

2.3. Agrometeorological modelling

Long-term daily weather records were obtained from the Belgian Royal Meteorological Institute for the period 1947–2012. The Ukkel