# Improved temperature for maize growth using clear polymer film

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## Abstract

Clear polymer films (CPF) are used as a supporting technology for maize production in a number of high latitude countries to promote higher soil and air temperatures during the early stages of crop growth. By providing frost protection and promoting early development, crops can be sown earlier and hence mature within the short growing season. A research program is currently underway in Australia to develop a degradable form of CPF suitable for use in broad-acre crop production. This paper reports on findings from a 12 month field trial conducted in southeast Australia into the effect of film on the growing climate under film. Daily temperature increases under the film barrier were strongly influenced by seasonal variations in day length, solar radiation intensity, soil water content and condensation build-up on the underside of the film, and can become supra-optimal for crop growth. Relationships between key ambient and headspace climate variables will be used in ongoing crop physiology studies and for assessing the seasonal and regional suitability of CPF technology.

## Key words

Temperature stress, Zea mays.

## Introduction

Within many regions of southern Australia, irrigated maize (*Zea mays*) production is limited by a combination of cold spring temperatures and summer heat stress. Maize germination and crop establishment occurs slowly and sporadically in soils below 12 °C (Bollero *et al*., 1996) and the crop is especially susceptible to frost damage during these early growth and the later silking stages (Sánchez *et al*. 2014). For this reason, maize is not planted until soil temperatures reach 14°C, which can delay sowing until early November in many regions of Tasmania, Victoria and southern NSW (Pembleton and Rawnsley, 2012). Southern Australian maize planted in late spring is more susceptible to heat stress from high summer temperatures during silking and anthesis. Heat stress during this early period of reproductive development increases pollen and ovary sterility and increases zygote abortion, reducing the yield potential of grain (Barnabas et al., 2008). The long duration of silage maize crops can also lead to frost damage during crop maturation in autumn, further reducing crop quality (Pembleton and Rawnsley, 2012).

Current management strategies for reducing cold and heat stress risk in maize include the manipulation of sowing time, varietal selection and through strategic irrigation. Another potential management strategy is through the use of degradable clear polymer film (CPF). CPF is made from a thin layer of impervious and stretchable petroleum-based polyolefin or bio-derived materials. Strips of this material are installed over a newly sown crop and the edges buried on either side with soil, where it increases enclosed air and soil temperatures by trapping outgoing terrestrial radiation (Miller and Bunger 1963), recycles evapotranspiration (ET) losses back to the soil (Dubois 1978), and captures and concentrate soil and plant $CO_2$ and $O_2$ emissions. The film remains intact for a period determined by the chemical composition of the film and the environmental conditions. Once the film breaks down (typically 30-50 days after sowing) the crop continues to grow normally. The higher temperatures under the film reduce early season cold stress and enable earlier sowing and faster crop growth (Walker, 1969). The subsequent advancement of flowering and crop maturation may also reduce heat stress risk at flowering and late season frost risk. CPF is currently used in northern Europe and Canada to promote faster and higher rates of maize establishment, and increased productivity and earlier maturation (Orzolek *et al*. 2000).

This paper reports on findings from a Tasmanian study into the growing environment under CPF and how the use of CPF may influence maize planting dates, as well as any seasonal limitations to the use of the CPF due to supra-optimal temperatures and excessive heat accumulation.

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## Materials and methods

A trial site was established in August 2013 near Cambridge (42.79°S, 147.42°E) in southeast Tasmania. Strips of clay soil (~4 m long X 2 m wide) to be covered with film were cleared of weeds and tilled uniformly in a north/south orientation to a depth of ~30 cm and irrigated to field capacity. The soil was shaped into a mound and covered with strips of UV stabilised, clear polyethylene propagation film (3 m long X 1.2 m wide X 10 µm thick) manufactured by Integrated Packaging Pty Ltd. Melbourne. The edges of the film overlay were buried to a depth of 15cm to create a sealed headspace.

Atmosphere/climate sensors were positioned under and adjacent to the film to capture trends in ambient and confined headspace temperature, solar radiation and relative humidity. Temperature and relative humidity were measured using a combined sensor (Campbell Scientific CS 215 probe) housed inside a louvered radiation shield. Ambient temperature and relative humidity were measured at ground level and at a height of 1.2 m to replicate the standard design of Bureau of Meteorology weather stations to enable direct comparison between headspace and ambient data, and for comparison against historical climate data (BOM, SILO databases). Solar radiation was measured with an Apogee pyranometer (SP110) covering the short-wavelength range of 360 to 1120 nm and a 180° field of view. The headspace pyranometer was placed 2 cm below the film in all treatments. Temperature, radiation and relative humidity were measured every 10 minutes and stored in a Campbell Scientific CR200X logger from which data was downloaded remotely via wireless access. The trial was run over 12 months (i.e. August 2013 to July 2014) to capture a wide range of ambient climate conditions.

## Results

The effect of CPF on heating and cooling processes fundamentally altered the daily temperature profile of the crop growing environment. Daily temperature fluctuations from solar heating occurred rapidly within the CPF-enclosed treatment, elevating maximum headspace temperatures by 15-40 °C above ambient environmental temperatures over the durationn of the trial. Headspace temperature increases were lowest during August and greatest during November, with maximum daily temperatures occuring within 5 hours of sunrise. In contrast, daily heating occured slower within the control treatment exposed to ambient conditions, requiring 8-9 hours to elevate daily surface temperatures by only 9.3 ± 3.1 °C. These daily fluctuations in temperature within CPF-enclosed headspaces correlated strongly with daily variations in incident solar radiation ($r = 0.523$, $n = 108$, $p < 0.001$).

These alterations to the rates of headspace heating and cooling altered the frequency and duration that headspace temperatures remained within temperature thresholds considered physiologically important for maize growth. For the control treatment, more than 30% of days between August 14th (day 227) and December 1st (day 336) failed to exceed 14 °C and enter the maize exponential growth response window described by Walker (1969) (Figure 1). Similarly, only 4.5% of days exceeded 23 °C (Figure 1), which marks the beginning of the optimal thermal kinetic window for maize growth (Mahan *et al*. 1990). In contrast, for the same period under CPF, temperatures exceeded 14 °C on all days, and exceeded 23 °C recorded on 91% of days. The application of the CPF-treatment also reduced the incidence and severity of sub-zero (frost) temperatures.

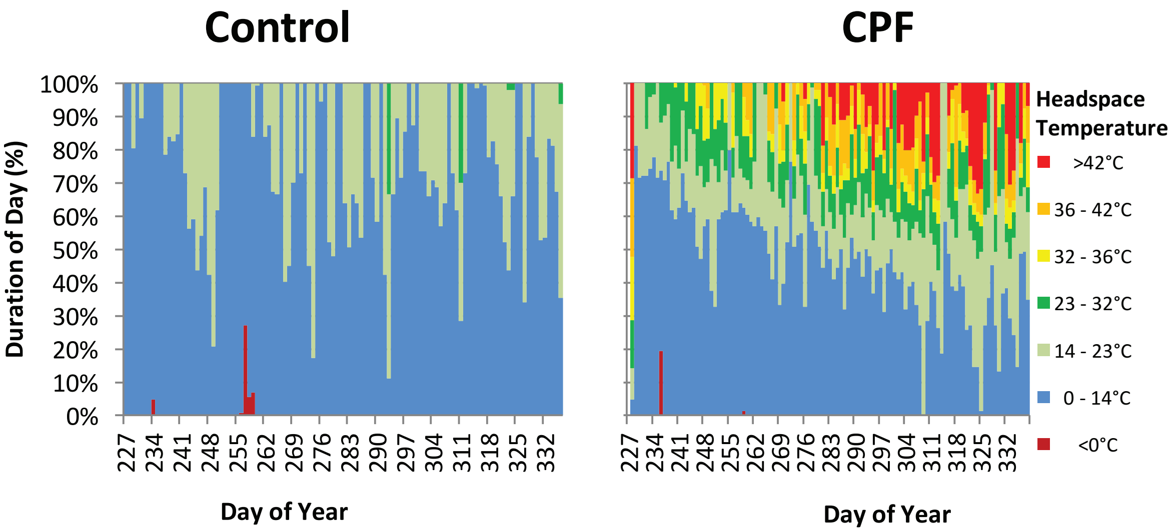

**Figure 1 Proportion of 24 hour period where headspace temperatures were below, within and above the optimal 23-32 °C thermal window for maize growth described by Mahan *et al.* (1990). Exposure to temperatures within the optimal temperature range and the exponential growth response window (14-23 °C) described by Walker (1969) were greater within the CPF-enclosed treatment increased seasonally. Exposure to supra-optimal (32-36 °C), acutely supra-optimal (36-42 °C) or potentially fatal temperatures (>42 °C) also increased in response to seasonal changes.**

## Discussion

Over the winter/spring period, the CTF film increased temperatures in the headspace to levels that would support maize establishment and productive growth and development. Over this period, headspace temperatures were within the optimal range for maize growth and development, 23-32 °C (Mahan *et al*. 1990) and the exponental growth response range of 14-23 °C (Walker 1969) for several hours each day. Without the protection of this insulating layer of CPF, headspace temperatures within the growing environnment were much lower than CPF enclosed films throughout the observation period, and on many days only a small percentage of each day exceeded the minimum cardinal temperatures required for leaf elongation (7.3 ± 3.0 °C), stem growth (10.9 ± 1.4 °C) and root growth (12.6 ± 1.5 °C) described by Sánchez et al. (2014). Due to the close proximity of these minimum cardinal values to maximum daily temperatures throughout this season, even small fluctuations in daily temperature maxima are likely to have a signficant influence upon the duration and efficiency of plant biomass production (Walker, 1969). In contrast, temperature conditions present beneath CPF film enable a more efficient and signficantly extended window for conversion of incident solar radiation into biomass production and plant development during this seasonal period (Mahan *et al*. 1990).

Inadequate heat dissipation and excessive heat accumulation during spring and summer months were also identified as potential issues for CPF-supported maize production within Australia. Over the period from August 14th to December 1st in this trial, 73% of days experienced headspace temperatures that were considered supra-optimal (32-36 °C) or acutely supra-optimal (36-42 °C) underneath the CPF film, and temperatures exceeding the lethal temperature threshold for maize (42 °C, from Birch *et al*. 1997) were recorded on 40% of days. Daily temperatures in excess of 32 °C were first observed during early September and increased in frequency, severity and duration in response to rapid seasonal changes in day length, solar energy intensity, ambient air temperatures and reductions in cloud cover density (Miller and Bunger, 1968). In regions with warm spring temperatures and a low incidence of spring frosts, such heat stress may be alleviated by either physical removal of the film or degradation of the film layer during early spring. Within colder regions where seasonal frost risks are higher and ambient conditions are less favourable for growth, removal of this film layer is likely to elicit an acute cold-shock response and expose early crops to potentially fatal environmental conditions (Sánchez *et al*.,2014). In these circumstances, the use of macro- or micro-perforated CPF films may be utilised to aid heat dissipation and limit temperature extremes without exposing the enclosed plants to frosts and other damaging conditions.

## Conclusion

By enclosing the growing environment beneath a CPF membrane, atmospheric heat losses can be reduced to minimise the impacts of crop cold stress upon maize seed germination, crop establishment and vegetative development during early-season growth. Within cold-limited production areas, use of CPF technology may enable the early establishment and growth of maize and other temperature-limited crop species during late winter and spring, enabling the growing season length to be signficantly extended. Simple modification of the technology may also facilitate wider seasonal usage and reduce the issues associated with excessive heat accumulation.

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