Soil temperature and soil water potential under thin oxodegradable plastic film impact on cotton crop establishment and yield

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\textbf{A R T I C L E   I N F O}

\textbf{Article history:}
Received 10 June 2015
Received in revised form 7 September 2015
Accepted 7 September 2015

\textbf{Keywords:}
Plastic mulch
Emergence
Lint yield
Fibre quality
Modelling
Cold days
Frost

\textbf{A B S T R A C T}

Field experiments were undertaken to determine the effect of oxodegradable thin film on cotton establishment and lint yield. It was hypothesised that the use of thin oxodegradable plastic film would increase soil temperature and conserve seedbed water possibly reducing the risk in early planting, while not reducing lint yield or fibre quality of cotton. Experiments were conducted near Narrabri, NSW Australia during the 2010, 2012–2014 and the 2012 and 2013 seasons near Griffith, a cooler region in southern NSW with three or four thin oxodegradable plastic films with different formulations and break down rates being compared with a bare soil treatment. Planting depth soil temperature and soil water potential was monitored at three hourly intervals. Soil temperatures were elevated by 2–4°C under the thin film compared with the bare soil that resulted in earlier (2–4 days) emergence of cotton under the thin film compared with bare soil. Soil also remained wetter beneath the thin film. Two films began to degrade at the time when cotton seedlings emerged (10–20 days), resulting in greater seedling survival (2–7 vs 12 plants/m). Seedlings were unable to penetrate four films on emergence and did not survive. These films were slit to allow seedling growth, survival depended on subsequent environmental conditions; whether over-cast/sunny or cool/warm conditions occurred. Using film that had been slotted prior to being laid in the field also increased soil temperature and conserved seedbed water. This enhanced (50–80%) emergence and survival of emerged seedlings, and overcame the need to slit film in the field.

A climate analysis and simulation study was also conducted to determine the benefit or otherwise of thin film and early planting over a longer-term than is possible from field studies. Results for both sites indicated that the earlier the planting date (August/September), compared to a "normal" planting date (October) there was a greater the chance of cold (6.5 vs 2.5 days) and frost (2.5 vs 0 days) being experienced, which resulted in lower or no lint yield. Lint yield tended to be greater (3200 vs 2800 kg lint/ha), although not significantly so, with thin film compared with bare soil. Fibre quality parameters were not affected by the use of thin film. All surface film had degraded by the end of the season posing no risk of contamination of the lint. Film below ground did remain intact, but this does not pose a contamination risk for the cotton lint at harvest. No plastic film was detected in ginned cotton after being machine harvested at both sites.

There was no significant benefit in lint yield due to thin film, while all fibre quality parameters made base grade. Long-term simulation of early planting, with and without thin film, indicated that lint yield was variable with no consistent benefit due to the presence of thin film for the locations simulated. There is still a risk of cold weather or frost occurring when planting early with thin film that growers need to consider. In practical terms it is anticipated that growers would potentially only plant 5% of their area early depending on the seasonal forecast.

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\url{http://dx.doi.org/10.1016/j.fcr.2015.09.009}
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\section{Introduction}

The use of mulches in agriculture is not a new concept as straw, leaves, gravel and composts have been used for centuries (Lightfoot, 1996). The recent development of new products such as plastic films offers new opportunities in the use of mulches. A major issue
with using plastic film as a mulch has been the problem of disposal as it did not degrade (Shogren, 2000), however, new formulations which degrade to water and carbon dioxide overcome this limitation. Also, there is potential environmental pollution from plastic mulches, which may have long-term consequences for soil conditions and human health (Chen et al., 2013). The degradation and potential pollution from plastic mulch depends on the type of film and the conditions under which it is deployed (Kyriou and Briassoulis, 2007). The newer oxodegradable film reduces the amount of plastic mulch currently being disposed in land-fill (Dai and Dong, 2014).

Thin plastic film has been used to increase soil temperature, conserve soil water and to improve crop establishment for crops such as maize (Zhou et al., 2009; Zhang et al., 2011; Liu et al., 2009, 2013), vegetables (Cavero et al., 1996; Waterer, 2010; Yaghi et al., 2013; Qin et al., 2014) and cotton (Statthakos et al., 2006; Dai and Dong, 2014).

Plastic mulch has previously been studied locally in Fusarium and black root rot control (Anderson et al., 2006; Nehl et al., 2004). During this time period oxodegradable plastic was not available and the plastic was considered to be a contamination risk to cotton fibre which results in significant penalties to the grower and the industry’s reputation. However, film can now be manufactured to degrade at a known rate so that emerging plants are not impeded (Kasirajan and Ngouajio, 2012), which presents an opportunity to examine new oxodegradable polymer films in cotton systems. It is postulated that using oxodegradable polymer films may allow earlier planting, improve crop establishment, improve early season growth, enhance water and nutrient use efficiency and reduce weed competition during crop establishment; the end result being increased lint yields. Benefits may be greater in cooler regions through elevation of soil temperatures and conservation of seedbed water enabling manipulation of season length, planting date or timing of harvest.

Thin films can induce diurnal effects on air and soil temperature (levels higher during the day and lower during the night) and carbon dioxide levels beneath the film when compared to a bare soil. These effects can be altered by the various additives that affect the film’s reflectivity, absorption and water passage through the film (Tarara, 2000). If the film is impermeable to water, evaporation from soil is reduced altering evapotranspiration (ET). There can be an advantage in rainfed situations by conserving available water and improved crop water use efficiency (WUE, kg lint/ha/mrn). This can assist with reducing seasonal variability associated with rainfall (Bu et al., 2013; Wang et al., 2009; Zhou et al., 2012). Under irrigation there is potential to reduce water use (ET) and increase WUE (Yaghi et al., 2013; Zhang et al., 2013), which will be attractive as the price of water increases or security of access to and supply of water decreases. Also, it may be possible to harvest rain water from the film covered areas (Li et al., 2008; Ruidisch et al., 2013). However, consideration would need to be given to field layout for runoff and erosion potential due to slope. Recently a biodegradable spray on mulch was developed as an alternative for thin plastic film for potential use in horticulture (Immirzi et al., 2009). This would allow the use of the product under stubble retained situations, when planting into wheat stubble for example.

This research was undertaken to examine the hypothesis that the use of thin oxodegradable films would improve cotton establishment in cooler cotton regions of Australia, conserve seedbed water and not decrease lint yield or fibre quality of cotton. The effect of early planting in conjunction with the use of thin film in two cotton regions of Australia was also examined using a cotton simulation model. The objective of this part of the study was to determine if thin film would reduce the risk of early planting over a longer time frame than is possible from field experiments and whether a crop would grow to maturity if it experienced periods of cold (air $T_{min}$ < 11°C) or frost (air $T_{min}$ < -2°C) at some time after emergence.

### 2. Materials and methods

Details of field experiments for each season at each site are summarised in Table 1. The film thickness was nine microns for film A–C and G and ten microns for film D, E, F1 and F2. Normal

<table>
<thead>
<tr>
<th>Site</th>
<th>Season</th>
<th>Treatments</th>
<th>Planted</th>
<th>Film slit</th>
<th>Irrigation</th>
<th>Plots</th>
<th>Cultivar</th>
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<tbody>
<tr>
<td>ACRI Expt 2</td>
<td>2012/2013</td>
<td>Control film: F1, F2 (3 Reps)</td>
<td>24/9/2012</td>
<td>3/10/2012</td>
<td>5/10/2012</td>
<td>3 rows by 5 m</td>
<td>Sicot 71 BRF</td>
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<tr>
<td>ACRI Expt 3</td>
<td>2013/2014</td>
<td>Control film: Spray-on (20% Na alginate soln.) (4 Reps)</td>
<td>12/9/2013</td>
<td>8/10/2013</td>
<td>13/9/2013</td>
<td>4 rows by 7 m</td>
<td>Sicot 71 BRF</td>
</tr>
<tr>
<td>ACRI Expt 4</td>
<td>2012/2013</td>
<td>Control film: F2</td>
<td>25/9/2013</td>
<td>18/10/2013</td>
<td>13/9/2013</td>
<td>3 rows by 5 m</td>
<td>Sicot 71 BRF</td>
</tr>
<tr>
<td>Expt G1</td>
<td>2013/2014</td>
<td>Control film: F2</td>
<td>3/10/2012</td>
<td>17/10/2012</td>
<td>7/10/2012</td>
<td>3 rows by 5 m</td>
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<tr>
<td>Expt G2</td>
<td>2013/2014</td>
<td>Control film: Spray-on (40% Na alginate soln.) (3 Reps)</td>
<td>17/9/2013</td>
<td>30/9/2013</td>
<td>22/9/2013</td>
<td>3 x 200 cm beds by 10 m</td>
<td>Sicot 74 BRF</td>
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</tbody>
</table>

Table 1: Site and experimental details for thin film experiments 2009–2014. All experiments were on 1 m row spacing.
agricultural film was not used due to concern about contamination at harvest and the fact that the film would be difficult to remove prior to harvest. The composition of the films is the confidential intellectual property of the suppliers. The films start to degrade on exposure to sunlight and water by becoming brittle and breaking into smaller pieces, eventually degrading through microbial action to the end product of water and carbon dioxide. Time to embrittlement for film E, F1, G and F2 was on average 27, 12, 27 and 45 days, respectively, after exposure to 25, 30, 28 and 26 MJ/m² per day. Different films were used for experiments depending on availability and development by manufacturers following field experience from previous experiments.

2.1. Narrabri (Australian Cotton Research Institute, ACRI), NSW

Field experiments were conducted over four seasons (2009/2010, 2011/2012, 2012/2013 and 2013/2014) on the Australian Cotton Research Institute (ACRI), Narrabri (149°40'E, 30°10'S), New South Wales, Australia on a grey self-mulching Vertosol (Isbell, 1996). The initial experiment assessed the range of degradation rates of available oxodegradable films (A–C and D) (experiment 1), while subsequent experiments examined a range of planting dates and films (E, F1, F2 and G) to assess cotton emergence and the ability of film to modify soil temperature and conserve seedbed water (experiments 2–4).

2.1.1. Factors common for all field experiments

Nitrogen fertiliser was applied as urea pre-planting at the rate of 180 kg N/ha. Weeds and insects were managed as per Bollgard® II protocol (Maas, 2014) and plots irrigated on the station schedule of an approximate soil profile water deficit of 70–80 mm. The average soil temperature at 0.1 m under the bare soil control and under the film was measured with J-type thermocouples (RS Australia) and the data logged every 3 h in experiments 1, 3 and 4, while tiny tag temperature sensors (Hastings Data loggers) were used in experiment 2. Soil water content was manually measured daily at 09:00 (to coincide with meteorological data records) with a probe (Delta-T, UK, 0.07 m) in experiment 1 and using calibrated GByte gypsum blocks (MEA, Australia, 0.1 m) in experiment 2 or logged every 3 h with MPS-2 combined water potential and temperature sensors (ceramic disc/thermistor, Decagon Instruments, 0.1 m) for all other experiments. Plots were monitored daily to determine emergence, whether seedlings had penetrated the film, final establishment, and for changes in the film, such as colour and appearance of lateral tears and to decide when to slit the film. Sensor malfunction resulted in no data for film C or the control treatment the two measurements registered at 15:00 and 18:00 for the control indicated a temperature of 21 °C, which is considerably lower than under the thin films in experiment 1 in 2009/10.

The crops were planted on the dates indicated in Table 1 with the thin film being placed by hand over the planted row on the following day (Fig. 1). The cotton cultivar Sicot 71 BRF (Stiller, 2008), germination percentage 96%, was used for all field experiments. The sensors for monitoring soil temperature and water potential were placed in a single replicate consisting of all treatments in three adjacent rows; to restrict the extent of leads to the logger from impeding field operations. All other replicates consisted of a single treatment in three adjacent rows.

The treatments compared bare soil as the control with the oxodegradable thin films and were laid out as a completely randomised block design. Cotton lint yield data and fibre quality were determined from hand-picked samples at maturity and were analysed using standard ANOVA at the five percent level with Genstat 13 (VSN, 2010). Soil temperature and soil water data were unable to be statistically analysed due to non-replication as a result of instrumentation restrictions.

2.2. Southern NSW region

Two field experiments (G1 & G2 respectively) were also established on Red Sodosols (Isbell, 1996) in southern NSW near Griffith (G1, 34°, 225′54″S, 145°46′36″E) in 2012/13 and one near Coleambally (G2, 34°, 415′22″S, 145°46′31″E), in 2013/14.

2.2.1. Factors common to field experiments

Details for experiments G1 and G2 are given in Table 1. The average soil temperature and water potential at 0.1 m in the bare treatment and under the film was measured with MPS-2 water potential and temperature sensors (ceramic disc/thermistor) and logged on a three hourly interval. Plots were monitored daily to determine emergence.

The cotton cultivar Sicot 71 BRF was used for experiment G1 and Sicot 74 BRF (Stiller, 2010) germination percentage 94% was used for experiment G2. The thin film was laid by hand the day after planting in G1 and the film was pre-slit prior to being laid mechanically on the day of planting in G2 (Fig. 1).

The treatments compared bare soil as the control with the oxodegradable thin films in G1 and the thin film and spray-on (a 40% solution of sodium alginate) in G2 and were laid out as a completely randomised block design. Individual treatments consisted of three adjacent rows. Cotton lint yield data and fibre quality were determined from hand-picked samples at maturity and were analysed using standard ANOVA at the five percent level with Genstat 13 (VSN, 2010). Soil temperature and soil water data were unable...
to be statistically analysed due to non-replication as a result of instrumentation restrictions.

2.3. Climate analysis and simulation

In conjunction with the field experiments, long-term climate data was used to determine the average number of cold days and frost occurrences for weekly plantings from September to November for Narrabri (ACRI) and Griffith (New South Wales, Australia). This was to determine whether early planted crops were more likely to be affected by cold or frost days which would determine crop survival and final lint yield. The effect of early planting along with the use of thin film was also examined for these two cotton-growing locations in Australia using the cotton simulation model, OZCOT (Hearn, 1994). The objective of the modelling exercise was to determine if thin film would reduce the risk over the long-term of early planting by allowing a more rapid emergence and establishment of a crop that would then go on to maturity, or whether the earlier emergence of a crop would result in it experiencing an increased occurrence of periods of cold days or frost after emergence that would result in reduced crop growth or a failed crop. In other words, if an early planted crop emerged more rapidly, would it survive potential cold or frost days through to harvest, or would growth be checked to an extent that lint yield was decreased? The crop development in OZCOT is driven by accumulated day–degrees (air temperature) which is calculated from available air temperatures while seed germination and emergence are driven by soil temperature: thin film increased soil temperature, so, an increase in the maximum and minimum air temperatures was applied to each planting month to reflect the increased soil temperature induced by the thin film between planting and emergence. The model reverted to using mean air temperature for crop development after emergence. For the Narrabri region, maximum and minimum air temperatures were increased by 2.0 °C and 2.5 °C respectively in August, 1.5 °C and 2.0 °C respectively in September, and 1.0 °C and 1.0 °C respectively in October. Similarly, for the Griffith region the increase in maximum and minimum air temperatures were: August: 3.0 °C and 4.0 °C; September: 2.0 °C and 3.0 °C; October: 1.0 °C and 2.0 °C, respectively. These increases reflected the increase in maximum and minimum temperature measured under the films. OZCOT includes a frost function which terminates young crops if the temperature drops below 2.0 °C. The simulations were conducted with the model’s frost function both engaged and disengaged to determine the effect on crops which, if not killed by frost, were still prone to compromised growth due to cold periods.

3. Results

3.1. Narrabri

3.1.1. Experiment 1

The time to breakdown of the films was similar since exposure to average radiation was in the range 25–30 MJ/m² for all films.

The maximum and minimum soil temperatures at the planting depth were higher under the films compared with the control (bare soil) (Table 2). Over the duration of measurement the average soil temperatures under the thin films were 2 °C higher than the suggested optimum (16 °C) at planting depth, while the temperature between the soil surface and film was in excess of 50 °C (Table 2).

The mean volumetric soil water content for the surface (0–50 mm) was not different between treatments, but was 0.6% higher under the thin film compared with the control (Table 2).

Emergence under the thin film occurred 4 days earlier compared with the control (data not shown). However, the survival of the emerged cotton was poor; 0.4–1.6 vs 13.4 plants/m (Table 3) due
to the high temperatures experienced in the space between the soil and the film (Table 2).

The film above emerged cotton seedlings was slit on 10 November (5 Days after Planting, DAP) in an attempt to promote their survival, while the section above the temperature sensors was not slit to allow monitoring to continue. However, by this stage the emerged cotton had desiccated and did not survive, resulting in no lint yield data being recorded for experiment 1. Slitting of the film resulted in accelerated breakdown of the film as wind caused shredding of the edges. This meant that no observations on how the brittleness of the film developed were possible as the exposed edges of the film were already torn into strips. Degradation of the film tended to be relatively rapid with most surface film having disappeared by 14 December 2009 (34 days). Sub-surface samples of plastic film were collected until picking of cotton. A general observation when collecting the sub-surface samples was that the film while maintaining integrity was weaker and tore more easily at each subsequent sampling time.

3.1.2. Experiment 2

Depending on planting date, the maximum and minimum soil temperature at planting depth was 1–2 °C higher under the film compared with the control temperature, but was not as high as the previous season due to this being an earlier planting (Table 2). The one exception was the minimum soil temperature from the first planting, which was 0.2 °C cooler beneath the film compared with the control. Soil water was monitored using GBLite gypsum blocks since the water probe (used in 2009) required drilling holes in the film to insert the sensor compromising the integrity of the film and the measurement of soil water. The soil was consistently wetter under the film (lower soil water potential) compared to the control (Table 2). Cotton emerged 3–4 days earlier under the film compared with the control plots (data not shown) and the number of emerged plants (plants/m) declined with the later planting dates as the seedlings were unable to penetrate the film and died compared with the control (Table 3). There was no statistical significant difference in lint yield or fibre length between treatments: fewer plants were larger under the film and maintained yield. However, fibre strength and micronaire was statistically significantly different between the film and control, as well as micronaire between planting dates (Table 3).

3.1.3. Experiment 3

The maximum and minimum soil temperatures for all planting dates were not consistent across all planting dates during the emergence phase with the maximum temperature under film covered plots being warmer, except for planting 2 (2/10/2012) which was cooler, than the bare soil and the minimum temperatures being the mirror image (Table 2). The third planting’s maximum soil temperature was 6.6 °C higher than the control, and the soil was drier. Measured soil water potential indicated that the film covered plots were drier than the bare plots for the first and third planting date (18/10/2012). This was due to early slitting the film to allow the seedlings to grow (Table 2).

Plant establishment was more uniform under the film compared with the control with the final establishment of 10–12 plants m⁻¹ being similar for all planting dates, except for F2 at the third plant date (Table 4). There was a significant interaction between planting date and treatment in plant establishment due to the combination of temperature under the film and soil water and timing of slitting the film, which resulted in seedling desiccation and non-survival of plants with the last planting date (Table 4). Lint yield and fibre quality are presented in Table 4. There were no significant statistical differences between planting dates or treatments in lint yield or fibre quality parameters, except for fibre strength, which significantly differed with planting date (all quality parameters met base grade for Australian cotton).

3.1.4. Experiment 4

The soil temperatures at all planting dates varied between 17 to 20 °C and then continued to rise between 26 and 28 °C over time (Fig. 2). The soil temperature under the control and spray-on treatment was similar, while the temperature under the film was consistently greater for all planting dates until the film was slitted. Thereafter, soil temperature in all treatments coincided (Fig. 2). The minimum soil temperatures were elevated between 0.5 to 1.3 °C under the film compared with the control or spray-on (Table 2).

Soil water potentials varied under all treatments up to the time that the film was slitted, with soil water potential lower under the film under the first and second planting and the bare lower under the third planting (Fig. 3). After the film was slitted the soil water potential under the film was higher than the other treatments under planting 1 (Fig. 3a) and lower under planting 2 and 3 (Fig. 3b,c). Over the period of measurement the soil water potential was greater under the film and spray-on for the first and second planting and lower for the third planting date (Table 2).

A similar number of plants established (5, 8, 6.3 and 6.6 plants/m) under all treatments for the first planting with a higher establishment under film (13.6 plants/m) with the second planting with similar numbers (10.6 and 11.1 plants/m) establish-
ing from the control and spray-on for the third planting (Table 4) compared with the other treatments. There was no statistical significant difference between treatments in lint yield or the fibre quality parameters of length and strength, while micronaire was significantly greater (4.9 and 4.67) with the thin film compared to the control and spray-on at planting 1 and the spray-on at planting 3 (Table 4).

3.2. Southern New South Wales

3.2.1. Experiment G1

There was a significant interaction between row orientation and treatment, with a greater final establishment (9.2 plants/m) on the N–S (North–South) rows under F2 (Table 5). Maximum soil temperature was greater under F2 (14.1 °C) and F1 (8.2 °C) for the E–W (East–West) and N–S rows respectively (Table 2) until the film was slit. Thereafter, the temperatures for both row orientations coincided. The film had a bigger effect on the soil maximum temperature (average 13.3 and 7.6 °C for E–W and N–S rows) compared with the minimum temperature (average 0.0 and 0.5 °C for E–W and N–S rows) (Table 2). Soil water potential indicated that the seedbed water was greater (300 kPa) under both films compared with the bare control for the E–W rows and was the same (−1 kPa) for the N–S rows over the ten day period for emergence; all seedbeds were in a dry down phase (Table 2). Once the films were slit the soil moisture began to dry, however the control dried more rapidly compared with the slit film under both row orientations (data not shown). More plants established under the film (8.8 vs 8.1 plants/m) compared with the control on the N–S with fewer plants establishing under the film (6.8 vs 9.7 plants/m) on the E–W rows (Table 5). Row orientation significantly influenced lint yield and fibre strength with N–S rows resulting in greater lint yield (2773 vs 1978 kg/ha, P < 0.001) with longer (1.25 vs 1.22 decimal inch) and stronger (34.5 vs 32.8 gm/tex) fibres P = 0.005 compared with E–W rows.

3.2.2. Experiment G2

This experiment was conducted under commercial conditions on a grower’s property to examine the effect of planting date on emergence and subsequent growth of cotton.

Soil temperatures were 1–2 °C greater under the film with little difference between the control and spray-on for all planting dates (Fig. 4). The minimum soil temperature was on average 2 °C higher under the film and 0.1 °C cooler under the spray-on compared with the control for all plant dates (Table 2).

Soil water potential was similar under all treatments over the period from planting to emergence (15–17 days after planting) at all planting dates (Fig. 5). For planting 3 there was a greater decrease in soil water potential under the control (−170 kPa) and spray-on (−450 kPa) compared with the film (Fig. 5c); this site was abandoned due to heavy weed infestation under the film. Planting 2 was a dry planting with the seedbed wet up by irrigation (Fig. 5b), while for the other planting dates cotton was planted into a wet seedbed. The soil at 0.1 m nearly dried to the crop wilting point (−1200 kPa) under the control, whereas the film only dried to −600 kPa at about 80 DAP (Fig. 5b).

There was a planting date by treatment interaction on lint yield with significantly greater lint yield at the early planting date compared with the second planting date (3026 vs 1900 kg/ha) and with yield being variable with treatments (Table 5). Planting date also significantly influenced fibre length and micronaire with increased length and micronaire occurring with the later planting (Table 5).

3.3. Climate analysis and simulation

The climate analysis results (1954–2014) indicated that the earlier the planting date the greater the risk of encountering periods of cold and frost at both Narrabri and Griffith (Fig. 6a,b). The number of cold days (from 6.5 to 3) and frost (from 2.4 to 0) decreased substantially around the normal target plant date of mid-October. Earlier planting with film also resulted in earlier emergence (15 days vs 40–25 days) compared with bare soil (Fig. 6c,d). This suggests that the seedlings which emerged early would be more likely exposed to cold and frost. The combination of early planting and the potential for cold and frost occurrence reduced lint yield and crop survival. As the planting date was delayed, lint yield decreased but crop failure was less likely. When the frost function was disengaged in the OZCOT model all crops survived to produce lint yield (Table 6). With the frost function engaged, early planted crops (August) which did survive produced slightly more lint yield under film compared with a bare planting at Narrabri (100 and 96% of yield potential) while early planted crops at Griffith (week 1 and 2 August planting) did not survive through to harvest (0% of yield potential) (Table 6). Yield reductions ranged from 1 to 7% of yield potential due to early planted crops experiencing a period of cold weather or frost post emergence. This was more pronounced at Griffith than at Narrabri.
However, as the planting date approached the normal target planting date (mid-October) there was a slight yield advantage with the film compared to bare soil at both sites (100% of yield potential, Narrabri and Griffith respectively, Table 6).

4. Discussion

Previous research on the use of plastic mulch in cotton were developing new farming systems for growing cotton in dry regions; cotton transplanted in furrows or on ridges on saline soils where the mulch was also used to harvest and conserve rainfall and drip irrigation or irrigation with saline water was utilised (Dong et al., 2007, 2008, 2009; Dai and Dong, 2014). This is in contrast to the current study which was evaluating the use of thin plastic film into an existing cotton farming system where cotton is mechanically planted on hills or beds and flood-furrow irrigation is the norm.

In this research, it was speculated that thin plastic film may offer the opportunity to plant earlier, by conserving seedbed soil water and increasing soil temperature. This may allow the expansion of the Australian cotton industry into areas that were previously...
Fig. 3. Soil water potential at planting depth (0.1 m) for (a) planting 1 (12 Sep 2013), (b) planting 2 (25 Sep 2013) and (c) planting 3 (3 Oct 2013) at the ACRI site (Experiment 4).
unsuited to cotton. Season length may also be increased, which may increase yield potential or allow for crop compensation as a result of insect or disease pressure and allow earlier picking thereby avoiding wet conditions at harvest.

This study builds on previous work conducted on the use of plastic mulch for solarisation and bio-fumigation conducted in Australia (Nehil et al., 2004). A major concern in the past with using plastic mulch was the potential for contamination of lint resulting in a down-grade in fibre quality. This has potentially been alleviated due to the above ground film completely degrading before picking.

The risk in planting cotton early often results in re-planting at an extra cost. It was speculated that thin plastic film would increase soil temperature and conserve seedbed water, resulting in rapid and uniform germination and emergence when cotton was planted earlier in the planting window. This is compared to a target plant date around 15 Oct when soil temperature is about 14 °C (at 0.1 m depth, measured at 09:00) and increasing over a three day period. An early planting under most Australian conditions would be considered to be the second or third week of September. The risk in

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Plant establishment, lint yield and fibre quality parameters at the Griffith G1 &amp; G2 experiments (LSD for significant factor(s)).</th>
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</thead>
<tbody>
<tr>
<td>Site</td>
<td>Planting date</td>
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<td>Expt (G1)</td>
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<td>Abandoned due to weeds</td>
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nd, not determined; trt, treatment.

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<th>Table 6</th>
<th>Simulated (1957–2014) average number of successful and failed crops planted under film and bare control and normalised lint yield (% lint yield for each planting week divided by the highest yield for that month) for weekly planting from August to October under frost and no (frost) conditions at Narrabri and Griffith, Australia.</th>
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Fig. 4. Soil temperature at planting depth for (a) planting 1 (17 Sep 2013), (b) planting 2 (30 Sep 2013) and (c) planting 3 (8 Oct 2013) at the Coleambally site (Experiment G2).

under the thin film compared with the non-film treatment, which agrees with previous studies in that the soil was wetter under plastic mulch than un-mulched treatments (Liu et al., 2009; Zhang et al., 2011). All treatments would be drying-down (between irrigations) or wetting-up (irrigated) at the same time, so relative differences in soil water potential would be maintained between treatments.

As the Australian cotton industry is highly mechanised it was thought that the film should be laid during the planting operation and no slit film was available at the time, so the initial experiments
Fig. 5. Soil water potential at planting depth for (a) planting 1 (17 Sep 2013), (b) planting 2 (30 Sep 2013 undefined) and (c) planting 3 (8 Oct 2013) at the Coleambally site (Experiment G2).
were undertaken to determine whether cotton could penetrate the existing films. The early experiments contrast with other research where the plastic mulch was slit on crop emergence (Dong et al., 2008), the plastic mulch was applied early or after planting and slit on crop emergence (Dong et al., 2009) or the crop was planted through holes in the plastic mulch (Dong et al., 2007; Qin et al., 2014; Yaghi et al., 2013) in that it examined the use of intact film of small thickness applied over planted cotton with the expectation that the seedlings would emerge through the film. The major outcome from the first experiment was the fact that cotton was unable to penetrate the films as they did not degrade in a time frame that coincided with cotton emergence (Experiment 1, Table 3). The first experiments at Narrabri, which were planted late in the target planting window, resulted in high cotton seedling mortality due to excessive temperatures between the thin film and soil surface and the inability of seedlings to penetrate the film. Humidity under the film was high and condensation was observed on the underside of the film. The combination of high temperature and humidity was the equivalent of ‘cooking’ the seedling. Similar observations were made by Anderson et al. (2006) and Nehl et al. (2004) when investigating the use of plastic mulch to solarise the soil for Fusarium and Black Root Rot control.

To enhance cotton emergence, equipment was developed by Stathakos et al. (2006) to plant and lay and perforate the film over the plant line in one operation. In a laboratory study Li et al. (2003) showed that 30% of holes in the film reduced evaporation from the soil surface by 12% compared with no film cover and the fewer the holes in the film the greater the amount of water conserved. They also demonstrated that the holes had little or no effect on soil temperature or water loss at depth. These results agrees with the results from the current study where soil temperature and soil water potential were not greatly affected under the film that was slit prior to application when compared with the control treatment at Griffith.

The climate analysis aimed to identify “planting-windows” that would minimise the risk of cold or frost on emerging cotton, thereby identifying an optimum window in which on farm experiments could be conducted to provide a risk assessment on the use of this technology. Reasons for changing the “normal” target planting-window vary from altering a harvest date to avoid wet conditions, to extend season length in cooler areas to providing time to plant an increased area within a planting-window. Results from the climate analysis suggested that there is a greater risk to encounter a period of cold or frost with an early planting date in the studied areas; the closer the crop is planted to a “normal” planting date potentially a greater benefit with film would occur as soil and air temperatures are on an increasing plane and the crop emerges earlier. This seems to be confirmed in Table 6 where between 98 and 100% of the yield potential was realised the closer to a “normal” planting date the crop was planted.

The long-term simulation was undertaken to determine the benefit or otherwise of using oxodegradable thin film in the longer-term compared to the relatively short-term of field experiments. Results indicated a highly variable response in lint yield due to
whether the emerging seedlings were exposed to cold or frost conditions. It is speculated that the slight lint yield advantage of the thin film would be insufficient to warrant the cost of purchasing and applying the film. For example if the film cost a grower about A$300/ha a yield advantage of 180 kg/ha of lint would be required on current cotton price (2014). The simulation results indicated potential yield advantages less than this. The risk of crop failure was greatest with early planting and this should to be considered when making a decision to plant early. From a practical view a grower would not plant the whole farm using thin film, realistically it may be feasible to plant 5% of the area early as a strategy to manage/manipulate picking time or circumvent the effect of cool soil temperatures to allow a greater area to be planted.

5. Conclusions

Soil temperature at planting depth increased and seedbed water was greater under the thin promoting earlier and uniform emergence of cotton seedlings compared control treatment, bare. There was no significant benefit in lint yield due to thin film, while all fibre quality parameters made base grade. Long-term simulation of early planting, with and without thin film, indicated that lint yield was variable with no consistent benefit due to the presence of thin film for the locations simulated. There is still a risk of cold weather or frost occurring when planting early with thin film that growers need to consider. Cold weather or frost encountered by the crop after emergence from under thin film will still impact the performance of that crop.

The first thin film formulations used did not allow cotton seedlings to penetrate the film and emerge, thereby negating any benefit of early and uniform emergence. Slotted thin film allowed seedlings to emerge, however, the film should be applied at plant- ing to ensure alignment with the plants. The exposed film degraded completely, which minimised the potential for plastic contamination of lint at harvest.

References


