## Reduced frost damage in wheat crops grown in delved soils

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### Abstract

Delving involves using wide bladed tynes to mix deep clayey subsoil with sandy topsoil. In wheat-growing areas of Australia with prevalent sand-over-clay soils, some growers use delving to improve crop growth and yield, primarily through putative enhancement of water and nutrient availability. One of the added benefits of delving is to reduce soil albedo and increase topsoil water holding capacity, thus increasing the potential for storage and release of heat and potential attenuation of the effects of radiative frost. Until now we had a very superficial understanding of the effects delving on frost reduction in wheat.

At Keith, a frost-prone location of South Australia, we investigated the effect of management practices with putative capacity to reduce frost damage, with emphasis on delving. Field experiments were established on paddocks where soils had 0.2-0.3 m water-repellent sand topsoil over clay subsoil.

In relation to crops in untreated control soil, delving increased yield from 1.9 to 3.1 t/ha in 2003, and from 0.5 to 1.5 t/ha in 2004. This large delving effect contrasted with the minor effects of other treatments including soil rolling, sowing rate, row spacing and cultivar mixture. Thus, there was a large increase in yield attributed to delving across a range of management practices.

Topsoil and canopy-height minimum temperatures were also consistently higher in the delved treatment. The average difference in canopy-height minimum temperature between delved and control treatments were 0.3-0.4?C, with a maximum of 1.6?C in 2003 and 1.2?C in 2004. A single, robust relationship between yield and frost damage fitted the data pooled across treatments and seasons. This, together with the temperature differential between treatments, and significant relationships between minimum canopy-height temperature around flowering and frost damage supported the conclusion that a substantial part of the yield gain attributable to delving was related to reduced frost damage.

### Introduction

Soils with sandy surface horizons and clayey subsoils are widespread in the Australian wheat-belt. In some of these sandy soils, hydrophobic particulate organic matter induces water-repellency (Franco et al. 1995), low infiltration rates and preferential flow paths (Harper and Gilkes 1994). Manipulation of soil characteristics and the heat bank can reduce expose of cereals to frost risk.

In this study, we assessed experimentally a number of agronomic management practices with potential to manipulate sand over clay soils in South Australia, thus mitigate frost damage and yield losses. The agronomic practices assessed included those that had the potential to reduce albedo, increase water-holding capacity, and in non-wetting sands, increase hydraulic conductivity. Some of these practices included, rolling to break up clods and compact topsoil to improve heat storage and transfer by decreasing soil porosity and increasing its thermal conductivity and heat capacity (Snyder and Melo-Abreu 2005). Delving to bring more clay materials to the soil surface of sandy soils and decrease water repellency. Manipulation of canopy density to maximize heat inception in the soil included practices such as wide row spacing, lower seeding rates and variety selection. Collectively, these practices may increase the potential for storage and release of heat and potential attenuation of the effects of radiative frost. Furthermore, it has been found that very small changes in minimum temperature at the ear level may have dramatic effects on wheat grain set (Marcellos and Single 1984).

In this study, particular emphasis was placed on delving, as growers interested in this practice and its actual effects on frost damage are largely unknown.

## Methods

Three experiments were established in paddocks east of Keith (36 $^{o}$S, 140 $^{o}$E, 98 masl), a frost-prone location in South Australia. Non-wetting sand soils had a 0.2-0.3 -m sand topsoil over a clay subsoil; Delving treatments were established the year previous to the experiment. In 2003 and 2004, the delving machine comprised three 1.3-m spaced blades (150 mm wide, 480 to 720 mm depth) that generated substantial mixing of the top soil, doubling the proportion of clay in the top 0.2 m. In 2005, a deep-ripper was used with smaller blades (80 mm wide, 600 mm depth); this treatment brings up less clay than the delver but allows clay to be ripped and some sand to drop into the cracks. A range of secondary treatments were combined with delving in each season. Each individual plot was 9 x 12 m. Treatments were arranged in a split-plot design with three replicates

*2003 experiment*

Crops were sown on 17 June and fertilised with 80 kg DAP per ha at sowing. A factorial experiment combined three cultivar variants, Krichauff, Yitpi, and a mixture of both, two sowing rates (50 and 100 kg/ha) and two soil treatments, delved and control. Soil treatment was assigned to main plots, and sowing rates and cultivar variants to subplots.

*2004 and 2005 experiments*

Wheat (cv Wyalkatchem) was sown on June 17, 2004 and 24 June, 2005, with, 80 kg DAP per ha. A factorial experiment combined two row spacings (0.2 and 0.4 m), two rolling treatments, i.e. rolled and unrolled, and two soil treatments, delved and control. Soil treatment was assigned to main plots, and row spacing and rolling treatments to subplots.

## Measurements and analyses

Temperature was measured and logged at 15 min intervals during the growing season using individually calibrated thermistors (650 7A) by Measurement Engineering Australia (Magill, South Australia). Measurements were taken at canopy height and on the soil surface in each plot. At maturity, plots were harvested with a 1.65 m wide header to determine grain yield. Protein content (near infra-red spectrophotometer Perten DA7000) and individual grain weight were measured in sub-samples.

Prior to harvest, 30 randomly selected heads per plot were examined and frost damage was calculated as the ratio between number of aborted grain and number of florets. As symptoms of frost could be confounded with those of heat stress, we evaluated the soundness of this measure of frost damage considering: (a) occurrence of hot days, i.e. maximum temperature above 31 $^{o}$C (Wheeler et al. 1996) in the four-week period centered in anthesis, and (c) the relationships between frost damage score and minimum temperature around flowering. The wheat module in APSIM (Keating et al. 2003) was used to estimate flowering time using locally calibrated parameters for the cultivars in each experiment and temperature data from Keith (Australian Bureau of Meteorology station 025507).

## Results

Grain yield averaged 2.5 t/ha in 2003, 1.0 t/ha in 2004 and 3.4 t/ha in 2005. Rainfall and evaporative demand in the critical months of September and October partially accounted for the three-fold range in seasonal yield. In 2003 and 2004, there were severe frosts around flowering which substantially reduced grain yield. Crops in delved soil consistently out yielded their counterparts in untreated soil (Fig. 1). All other treatments had small effects on yield, frost damage and soil and canopy temperature (not shown). In 2005, none of the treatments affected grain yield. The lack of yield response to delving was partially attributable to a lack of frost occurring and failure to properly establish the treatment. Hereafter, we concentrate on the effects of delving in 2003 and 2004.

*Grain yield and its components*

In 2003 and 2004, there were severe frosts around flowering which substantially reduced grain yield. In 2003, crops in delved soil yielded 3.1 ? 0.11 t/ha compared with crops in untreated soil, which produced 1.9 ? 0.14 t/ha. In 2004, crops in delved soil yielded 1.5 ? 0.05 t/ha compared to crops in untreated soil, which produced 0.5 ? 0.05 t/ha.

A number of factors may mediate the effect of delving on yield, including change in soil surface color and temperature, increased availability of nutrients and water, and reduction of soil mechanical impedance. The relationships between grain yield and its components, and frost damage indicated that a substantial part of the effect of delving in our experiments was related with reduced frost damage. In 2003, frost damage in crops grown in delved soil was typically below 20% whereas their counterparts in untreated soil ranged from 20 to 60%. In 2004, frost damage for crops in delved soil ranged from 6 to 45% compared to their counterparts in untreated soil with damage between 47 and 98%. Pooling the data of both seasons, frost damage accounted for 83% of the variation in grain yield (Fig. 1). Grain number accounted for most of the variation in grain yield. Grain size contributed to further reduction in yield of crops where frost damage was over 50%.

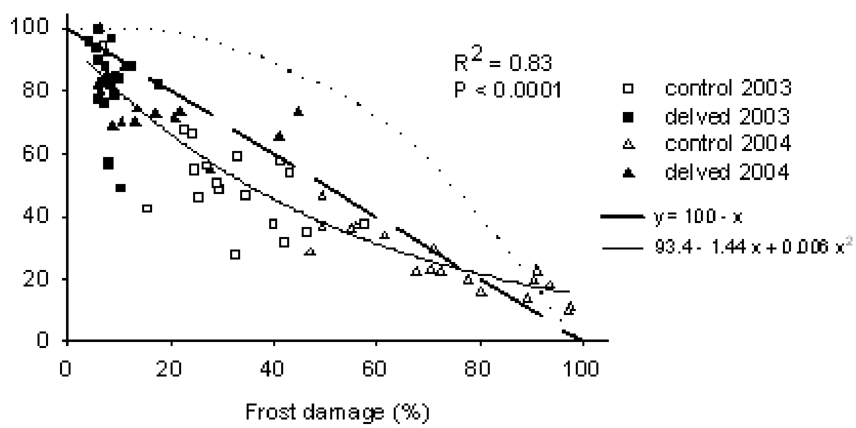


**Figure 1. Relationships between grain yield and frost damage at Keith in 2003-04 combined using a normalised yield scale. Solid lines are fitted regressions. The dashed line represents perfect proportionality between frost damage and yield loss, i.e. 1% damage causes 1% yield loss, and the dotted curve shows hypothetical compensation as proposed by Sadras *et al*. (1999).**

*Grain protein concentration*

Grain protein concentration increased with frost damage (not shown). The effect of frost on protein concentration was accounted for by the inverse relationship between yield and frost damage (Fig. 1) and the inverse relationship between yield and protein concentration (2003: r = -0.71, P < 0.0001; 2004: r=-0.94, P < 0.0001).

*Soil and canopy-height temperature*

In control crops, there were 26 days when canopy-height minimum temperature was below 0 $^{o}$C in 2003 and 21 days in 2004. Soil and canopy-height temperature were consistently higher in the delved soil treatment. The average difference in canopy-height minimum temperature between delved and control treatments were 0.3-0.4 $^{o}$C, with a maximum of 1.6 $^{o}$C in 2003, and 1.2 $^{o}$C in 2004. In the four weeks bracketing flowering, canopy-height temperature was below 0 $^{o}$C on twelve days in 2003, and on five days in 2004. These low-temperature events were consistently less severe in the delved treatment. In the week prior to flowering, there were no records of maximum screen temperature above 31 $^{o}$C in 2003, and maximum temperature above this threshold for pollen sterility (Wheeler et al. 1996) was recorded in two days in 2004. Hence, low and high temperature around kernel set could be confounded in our scoring of “frost” damage, particularly in 2004. There was, however, a significant correlation between percentage frost damage and the lowest temperature at canopy height in the critical period of four weeks around flowering (Fig. 2). This supports the interpretation that frost damage scores were truly reflecting this phenomenon in our experiments

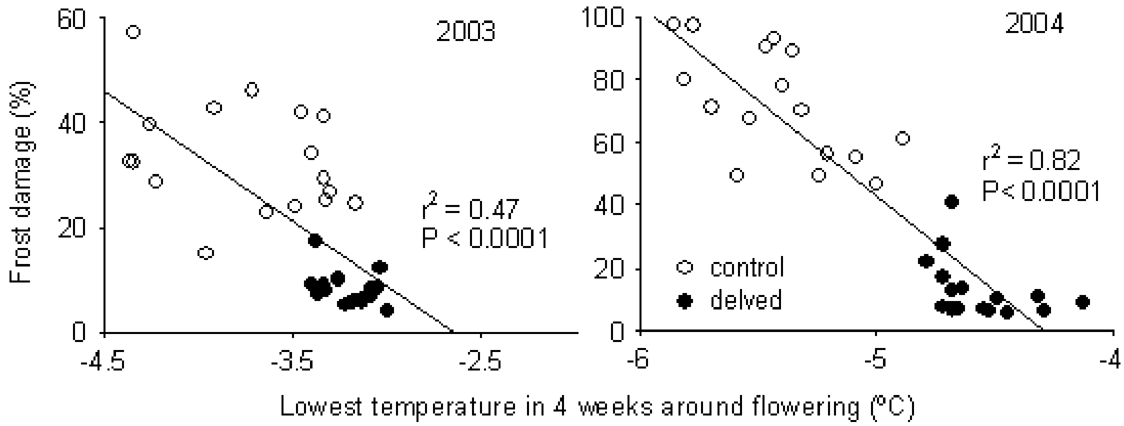


**Figure 2: Relationship between frost damage and the lowest canopy-height temperature in the four weeks around flowering for crops at Keith in 2003 and 2004. The fitted lines are: y = -66.1 – 24.9 x (2003) and y = -260.1 – 60.7 x (2004).**

## Discussion/Conclusions

*Effect of delving on temperature, frost damage and yield*

We found a consistent increase of grain yield in wheat crops grown in delved soil, with minor effects of other treatments including rolling, sowing rate and cultivar mixture. Importantly, lack of significant interactions between treatments indicated a robust response to delving across a range of management practices. Three putative factors may account for the yield benefits of delving: (i) increased water and nutrient availability in topsoil, (ii) reduced mechanical impedance due to soil ripping, and (iii) reduced frost damage. Lack of background measurements (e.g. harvest index, soil water and nutrients) precludes a definite allocation of effects to each of these factors. Based on the following arguments, however, we propose that reduced frost damage accounted for a substantial part of the delving effect in our experiments.

First, the magnitude of yield response, up to three-fold, is incommensurate with the relatively minor effect in water and nutrient availability expected from re-distribution of clay in the topsoil. Estimates of maximum soil plant available water for the experiment in 2004 indicate negligible differences between treatments. This suggests that the nutrient and plant water availability component of delving in our study, if any, was minor. Increased infiltration rate expected from claying (Harper and Gilkes 1994) and greater water holding capacity in the top 0.20 m of soil may have contributed to water and hence heat storage.

Second, the delving treatment, in addition of lifting clay from the subsoil to the soil surface, might have alleviated subsoil compaction. In sandy-loam Mallee soils, deep ripping could increase wheat grain yield by up to 40% (Sadras et al. 2005). Thus, part of the effect of delving in our study may be attributable to its effect on soil impedance. Third, detailed measurements of soil and canopy temperature frost scores and grain yield provided direct evidence of an important alleviation of frost in crops grown in delved soil. Importantly, the magnitude of the increase in canopy-height temperature attributable to delving, on average 0.4?C with a maximum of 1.2-1.6?C, was sufficient to substantially improve kernel set and yield (Marcellos and Single 1984).

The robustness of the relationship between yield and frost damage contrasts with the strong seasonal effect on the relationship between minimum temperature and frost damage (Fig. 2). Whereas frost damage increased linearly with decreasing minimum temperature in both seasons, the parameters of the fitted lines were quite different, e.g. the threshold temperature for damage was -2.6?C in 2003 and -4.2?C in 2004. In the experimental conditions of Marcellos and Single (1984), the threshold for grain set reduction was around -3?C.

The relationship between minimum temperature around flowering and frost score together with the few episodes of heat stress around flowering supports the validity of our measure of frost damage. Frost damage, in turn, accounted for most of the variation in grain yield, with a clear discrimination between delved and undelved controls in the relationship between frost damage and yield. While critical experiments are required for a conclusive isolation of the components of delving affecting grain yield (e.g. response to delving in the absence of frost), indirect and direct evidence in this study supported the notion that delving can contribute substantially to yield stability in frost-prone areas.

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