Opportunities for summer crops in non-irrigated winter cropping systems in southern Australia

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Abstract
Current wheat-canola cropping systems in the High Rainfall Zone of Victoria do not utilise rain that falls between mid-grain-fill in November and the following sowing in April or May. Analysis of these cropping systems showed six potential sowing times for opportunistic summer crops between winter crops. Simulated median soybean yields were 1.0 to 1.6 t/ha at Hamilton and 0.5 to 0.7 t/ha at Rutherglen, with higher yields for sowing in November than December. Field experiments at these locations are testing the potential of growing a summer crop in rotation with winter crops to convert unused rainfall to grain yield. The higher-yielding sowing windows for the summer crop coincide with when the winter crop is still in the paddock, so methods such as windrowing will be needed to remove the winter crop, or earlier-maturing winter crops.

Keywords
Soybeans, APSIM

Introduction
The wheat-canola cropping system that currently dominates the High Rainfall Zone (HRZ) grain zone of Victoria was adapted from neighboring drier regions and does not utilize rain that falls over the summer period. Opportunistic summer cropping may be a way of utilizing this resource, provided it does not compromise management, growth, or yield of the main winter crop. Optimal rotations of summer and winter crops have been developed for the northern grain zone (Hochman et al. 2020) but not yet for the southern regions. This paper first defines key dates in the current system to determine potential planting windows for summer crops. Secondly, data are presented on the fate of rainfall received outside the winter crop growing season. Thirdly, modelling is presented on yields from soybeans sown at the various planting windows. Finally, preliminary results are presented for soil moisture available at sowing from a field experimental program.

Methods
Current system
To describe the current system, key dates of management and phenology were analysed from the website of the National Variety Testing (NVT) program for the period 2015-2019 (https://www.nvtonline.com.au). This program is designed to replicate current practice, and faces similar logistical constraints on management operations as commercial farms. Sites in the HRZ grain zone selected were Hamilton, Lake Bolac and Rutherglen. For wheat, the NVT dates of sowing, anthesis and harvest were averaged across all varieties in each site-year, while for canola the equivalent dates were sowing, 50% flowering, desiccation, and harvest.

Soil moisture
Soil moisture data at depths of 30 cm to 1 m in 10 cm increments were measured by a capacitance soil moisture sensor (EnviroPro, Entelechy Ltd, Golden Grove, South Australia) in a continuous cropping paddock near Hamilton 2013-2020. Since a site-specific calibration had not been undertaken, readings were converted into a relative scale between the driest and wettest profiles observed over the recording period. To supplement this data set for near-surface (< 30 cm) moisture following late spring rainfall, data were included from an experiment with wheat on the Hamilton SmartFarm where there was a continuous record of soil moisture (EnviroPro) from a profile-filling rainfall event during mid grain-fill in November 2017 into the fallow period until February 2018.

Modelling
The APSIM crop model (Hochman et al. 2020) was used to identify sowing opportunities and simulate yields for a summer crop of early-maturing soybeans at Hamilton and Rutherglen over the period 1957 to 2020. Sowing opportunities were defined as 3 days of cumulative rainfall which reached 15 mm over the periods 15 Oct - 5 Nov (Sow1), 5-25 Nov (Sow2), and 1 -15 Dec (Sow3).

Field experiments
In May 2019 field experiments were sown at Hamilton and Rutherglen to test six potential sequences of a winter crop followed by a summer crop. These were wheat cut for hay in October or November followed by either (i) soybeans or (ii) safflowers; barley for grain followed by (iii) soybeans or (iv) safflower; wheat for grain with either (v) soybeans sown between the rows in October or November, or (vi) a summer fallow (control). This experiment has continued into 2021, but data are only presented for soil moisture at the time of sowing of the summer crop in 2019.

Results
Current system
Winter crops in the NVT were sown between late April and early May (Table 1). Anthesis in wheat occurred in late October at the southern sites of Hamilton and Lake Bolac, but nearly a month earlier at Rutherglen. Canola was desiccated at the southern sites in late November and 3 weeks earlier at Rutherglen. While the NVT trials were chemically desiccated, the most common practice is to cut and windrow at the same crop stage. Wheat was harvested 11 weeks after anthesis, while canola was harvested 3 weeks after desiccation.

Table 1. Average dates of key cultural operations and phenology in the National Variety Testing program at sites in the Victorian HRZ.

Site	Crop	Sowing	Anthesis/50% flowering	Desiccation	Harvest
Hamilton	Wheat	26-Apr	25-Oct		10-Jan
Lake Bolac	Wheat	24-Apr	26-Oct		17-Jan
Rutherglen	Wheat	2-May	28-Sep		16-Dec
Hamilton	Canola	1-May	13-Sep	24-Nov	14-Dec
Lake Bolac	Canola	27-Apr	13-Sep	25-Nov	15-Dec
Rutherglen	Canola	3-May	28-Aug	3-Nov	24-Nov

Soil moisture and rainfall
Over the summer period between December and March in most years there is neither replenishment nor rundown of soil moisture in the 30-100 cm layers (Figure 1a). In nearly all years the profile filled over the winter period, and in most years exhibited a sustained winter maximum that is indicative of waterlogging. Following a profile-filling rainfall event in November 2017 moisture at the 10 and 20 cm depths declined in December and January during the fallow period (Figure 1b), whereas at deeper depths it was retained until the next winter season (Figure 1a, Figure 1b).

Modelling
The simulated median soybean yield at Hamilton ranged from 1.56 t/ha for Sow1 to 1.06 t/ha for Sow3 for years where a sowing opportunity was identified, while equivalent values for Rutherglen were 0.70 and 0.47 t/ha (Figure 3). There was no sowing opportunity within Sow3 at Hamilton in 5% of years and Rutherglen in 14% of years. Crop maturity dates at Hamilton were 9 March to 6 April for Sow1 and 30 March to 17 April for Sow3, with equivalent dates for Rutherglen of 13 February to 30 March for Sow1 and 25 February to 6 April for Sow3. Some of these later crop summer maturity dates allow less than the recommended 4-week green bridge break for pathogen control prior to the normal sowing dates for the winter crop.

Field experiment
There was a trend for lower soil moisture at the later sowing date at Hamilton, whereas at Rutherglen the later sowing date had significantly more soil water (12 mm), which was attributable to rainfall (40 mm) between the sowing dates (Table 2).

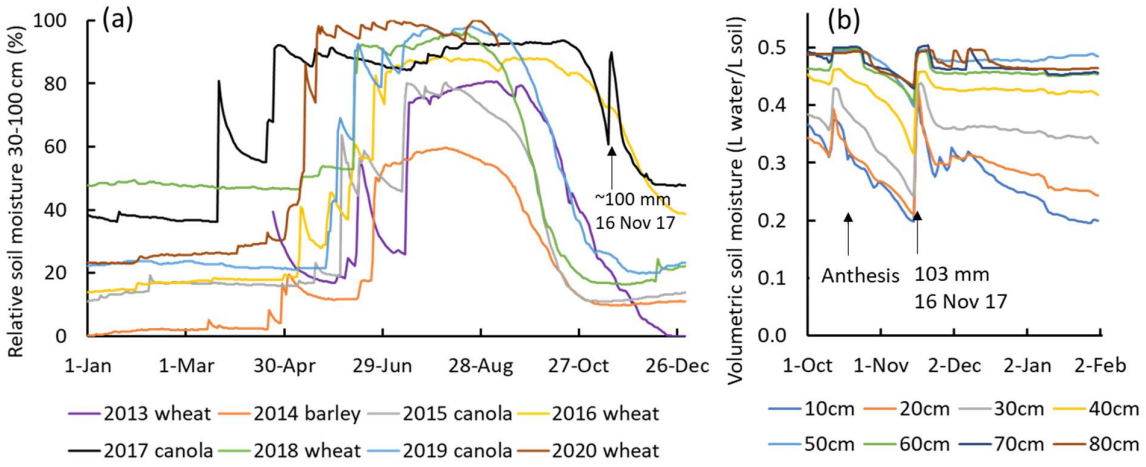

Figure 1. (a) Relative soil moisture 30-100 cm over 7 years in a continuous cropping paddock near Hamilton; (b) Soil moisture in a wheat experiment at Hamilton following a profile-filling rainfall event during grain-fill in 2017.

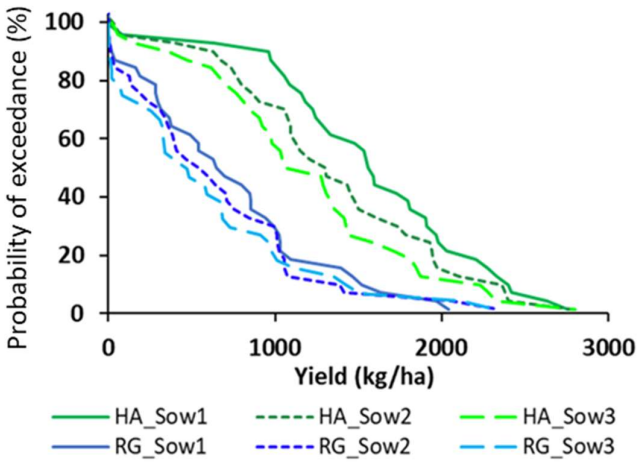

Figure 2. Probability exceedance for soybean yield at three sowing windows of a wheat-soybean-canola rotation at Hamilton (HA) and Rutherglen (RG) simulated for 63 years from 1957 to 2020. Sow1: 15 Oct - 5 Nov; Sow2: 5-25 Nov; Sow3: 1 -15 Dec.

Table 2. Soil water 0-1 m (mm) at the time of sowing summer crops at Hamilton and Rutherglen in 2019.

Treatment	Hamilton		Rutherglen	
	Date	Soil water (mm)	Date	Soil water (mm)
Wheat (hay) - soybeans	12 Nov	355	17 Oct	155ab
Wheat (hay) - safflowers	12 Nov	349	17 Oct	154a
Barley - soybeans	13 Dec	300	20 Nov	172c
Barley - safflowers	13 Dec	329	20 Nov	165bc
Wheat – soybeans intersown	12 Nov	354	17 Oct	160ab
lsd 5%		53 (ns)		10

Discussion

Data presented here indicate that in the HRZ rainfall received from late grain-fill in wheat or after desiccation in canola is poorly used in the current production system. Rain that does not penetrate below 30 cm, mostly from small events, appears to be lost to soil evaporation. Simulations of a soybean summer crop show a median yield of 0.5 to 1.5 t/ha and lower yields with later sowing windows, so there is an advantage in removing the winter crop quickly to sow the summer crop. Sowing after 15 December increases the risk that sowing of the following winter crop will be delayed. Soybeans were chosen for the simulations because of a well-developed model in APSIM, but findings are expected to apply to other summer crops such as

safflowers. Opportunities to remove the winter crop and likely dates for the start of each sowing window at Hamilton and Rutherglen are as follows:

		Hamilton	Rutherglen
1.	Frosted wheat cut as a hay crop shortly after anthesis. The area between the hay windrows is then available for sowing a double crop, notionally one week after anthesis.	1-Nov	5-Oct
2.	Once the wheat hay crop has been baled and removed the area that was covered by the windrows is available for sowing, notionally 3 weeks after anthesis.	15 Nov	19-Oct
3.	Canola is normally windrowed in the HRZ, after which the area between the windrows becomes available for sowing a summer crop.	24-Nov	3-Nov
4.	During grain-fill of wheat a summer crop could be sown between the wheat rows, notionally 2 weeks after anthesis.	15-Nov	12-Oct
5.	While wheat is not normally windrowed in the HRZ, it is a potential option. Physiological maturity is typically 30 days after anthesis, which approximately coincides with the time canola would be either desiccated or windrowed, after which a double crop could be sown between the windrows	24-Nov	3-Nov
6.	Once the windrowed canola or wheat crop has dried and been harvested, the area that was covered by the windrows becomes available for sowing a double crop.	14-Dec	24-Nov
7.	After the wheat harvest.	10-Jan	16-Dec

The last option is problematic in southern Victoria because an early January sowing of a summer crop is too late for it to be ready for harvest in time to plant the main winter crop in late April.

Conclusion

Double cropping in the Victorian HRZ has sowing opportunities in at least 86% of years, and median simulated soybean yields of 0.5 to 1.5 t/ha. However, the highest yields are for sowing times when the main winter crop is still occupying the paddock, so strategies for earlier removal such as windrowing, grain drying, or early-maturing winter crop varieties will be necessary to accommodate a summer crop.

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