Adapting irrigated and dryland farming systems to climate change and extreme weather events: is simplification or intensification more effective?

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Abstract

Past research has advanced our knowledge of climate change impacts on grassland production and crop yields, yet the resilience of whole farm systems to climate change remains to be quantified. Here we examine how climates in 2040 influence the production and animal feed requirements of dryland and irrigated dairy farms in southern Australia, then contrast the resilience of adaptations that simplified or intensified baseline farm inputs and management. The effects of farm system simplification or intensification on seasonal pasture growth rates in mitigating adverse effects of climate change were small. Relative to historical climates, annual pasture production and livestock pasture consumption in 2040 on dryland farms decreased by ~11% under baseline management or intensification, whereas adaptations that simplified systems resulted in little change in pasture production, pasture consumption or the need to purchase hay. The impact of climate change on annual pasture production and livestock pasture consumption of irrigated farms was less than that for dryland farms. In 2040 the need to purchase hay on the irrigated farm increased by 41% or 104% under baseline management or farming simplification, whereas purchased hay requirement under both historical and future climates under intensification was similar. Collectively these results suggest that the most effective adaptations in mitigating the effects of climate change on dryland and irrigated farms were simplification and intensification, respectively, but future work should address how climate and adaptation scenario influence profitability and risk.

Key Words

Extreme events, adaptation, dairy farm, sustainable intensification, climate change, pasture, milk

Introduction

While the impacts of climate change on crop and pasture production have been scrutinised for some time, knowledge of climate change impacts on whole farm production is in its infancy. A recent review highlighted the dearth of work examining the influence of climate variability on the timing of climatic stresses on pasture growth, and how such effects cascade through whole farm systems to impact on livestock production (Thornton *et al.* 2014). There is yet a paucity of information detailing how dairy farms might adapt to climate change. While there have been some reductionist studies documenting the effect of a single factor on production (e.g. stocking rate or pasture species), literature on the impacts of adaptations at the whole farm level are rare. Studies applying a more holistic approach by examining adaptations that incorporate simultaneous changes in several variables are even more scarce.

The present study was conducted as part of a larger multidisciplinary research project currently in progress (http://www.dairyingfortomorrow.com/uploads/documents/file/DBFFC/Dairy%20Business_NOV %20A4%20Newsheet_FINAL_1114.pdf). Two whole farm adaptations to climate change were designed for a dryland and an irrigated case study farm, and a new method was developed for generating future climate data containing increased frequencies of extreme events (Harrison *et al.* 2015). Farm systems were simplified or intensified relative to baseline management under current climates, with simplification reducing fertiliser inputs, herd size and purchased feeds, and with intensification increasing fertiliser applications, herd size, purchased feeds, and/or animal liveweight (Table 1). The purpose of this study was to determine whether farm system simplification or intensification served as a more effective adaptation to climate change.

Methods

Simulations were conducted using a whole farm model for a dryland dairy farm in Victoria (Moe; 38.17°S, 146.27°E) and for an irrigated farm in Tasmania (Wynyard; 41.00°S, 145.72°E). Baseline farm data and reports (monthly milk production, supplementary feed use etc.) were used to parameterise the model. Adaptations were designed iteratively by project teams and were intended to either simplify or intensify farm

Table 1. Data used to simulate the impacts of historical and future climates (2040) for two locations for case study farm management (baseline) and for adaptations that simplified or intensified baseline systems.

	Baseline		Simplify		Intensify	
Moe, Victoria	**Historical**	**2040**	**Historical**	**2040**	**Historical**	**2040**
Nitrogen fertiliser (kg N/ha/year)	189	172	120	150	224	203
Adult milking cows	352	352	200	200	500	500
Cow liveweight (kg)	475	475	475	475	550	550
Stocking rate (cows/ha)	3.2	3.2	1.9	1.9	4.5	4.5
Calving time	Spring	Spring	Autumn	Autumn	Split[A]	Split[A]
Whole farm area (ha)	175	175	175	175	175	175
Wynyard, Tasmania						
Nitrogen fertiliser (kg N/ha/year)	251	236	150	143	267	257
Adult milking cows	450	450	350	350	600	600
Cow liveweight (kg)	500	500	500	500	500	500
Stocking rate (cows/ha)	3.0	3.0	2.3	2.3	4.0	4.0
Calving time	Winter	Winter	Winter	Winter	Winter	Winter
Whole farm area (ha)	150	150	150	150	150	150
Irrigated area (ha)	100	100	100	100	150	150
Irrigation amount (ML/ha)	2.05	2.17	2.05	2.17	2.07	2.19

[A] Fifty percent of the herd calved in spring and 50% calved in autumn

systems (Table 1). Climate data from 1975 to 2013 were sourced from http://www.longpaddock.qld.gov.au/silo. A new approach was developed for simulating 2040 climate data that contained longer drought, more intense rainfall events and increased severity of heat waves relative to historical climates (Harrison *et al.* 2015). The approach incorporated both the Representative Concentration Pathways 8.5 projection for gradual climate change as well as our new method of generating increased frequencies of extreme events. At Moe, average annual rainfall decreased from 940 mm historically to 840 mm in 2040; at Wynyard historical rainfall was reduced from 995 mm to 932 mm in 2040. At both locations the decline in rainfall was relatively uniform across months. Monthly average minimum and maximum temperature at both sites increased by ~0.5°C and ~1°C respectively, with the greatest increases between January and April. Atmospheric CO_2 concentrations were set at 380 ppm and 490 ppm for historical and future climate data, respectively.

Results

Pasture growth rates on the dryland farm

Higher temperatures in 2040 elevated pasture growth rates in winter and spring, but growth rates in other seasons were reduced relative to historical climates due to the combination of more heat waves and longer drought periods (Figs 1a-c). Under historical climates, both adaptations reduced peak growth rates in spring relative to baseline management (dashed curves in Figs 1a-c). Climate change reduced annual pasture production of the baseline and intensification scenarios by 11% and 9% respectively, but had minimal effect on annual production under the simplification scenario (data not shown).

Pasture growth rates on the irrigated farm

Climate change increased growth rates on the irrigated farm in winter but reduced growth rates in other seasons (Figs 1d-f). Seasonal growth rates under simplification were relatively flat throughout the year, whereas growth rates under intensification increased relative to baseline management in spring, summer and autumn due to the combination of higher temperatures, greater nitrogen fertilisation and greater farm area under irrigation (Table 1). Despite large differences in annual pasture production under historical climates in each scenario (15.5, 11.1 and 17.9 t DM/ha/year for the baseline, simplification and intensification scenarios, respectively), the effect of climate change on annual pasture production was small in all management scenarios, averaging -2%.

Influence of climate change on pasture consumption and purchased feed at the dryland site

For the baseline and intensification scenarios, milking area pasture consumption at the dryland site was reduced by ~11% relative to the same scenario under future climates, whereas consumption remained relatively stable under climate change in the simplified farm system (7.8 t DM/ha/year, Table 2).

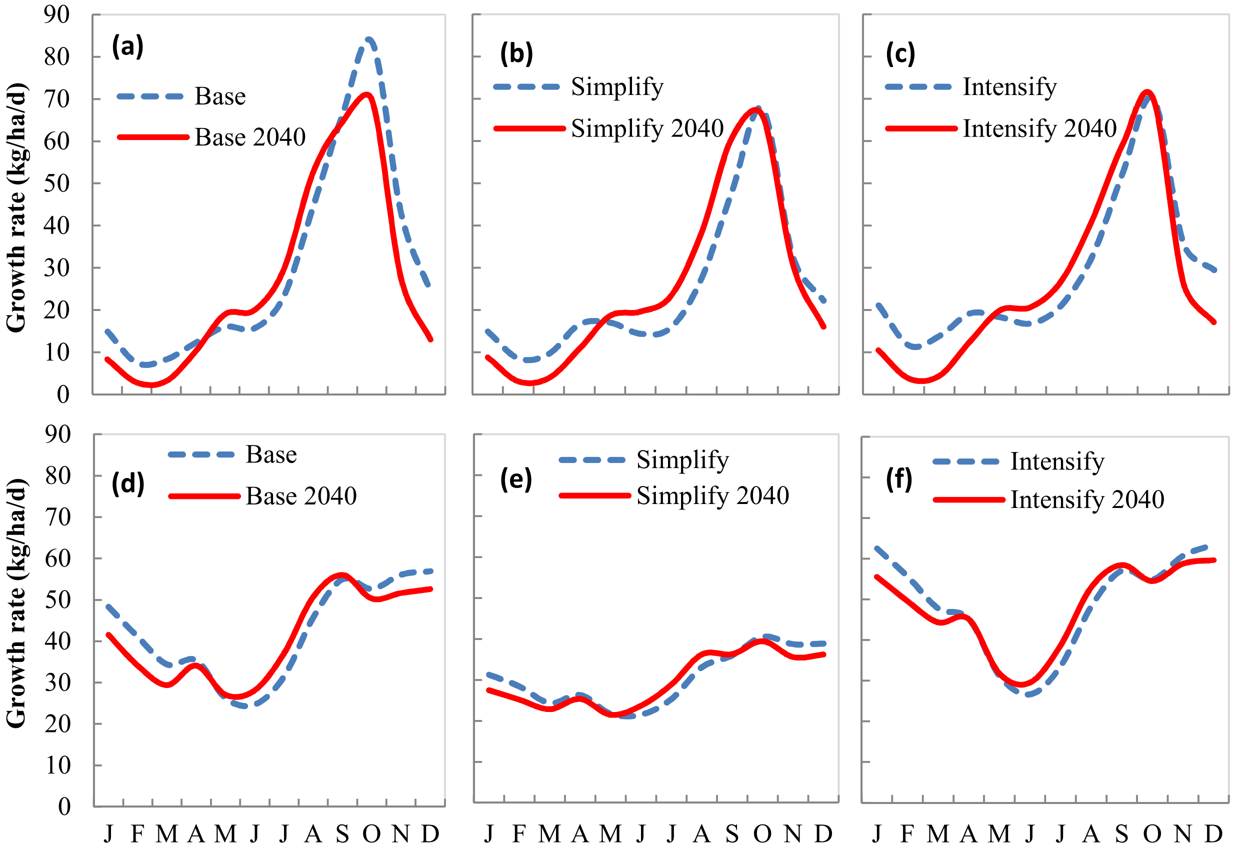

Figure 1. Average monthly pasture growth rates for dryland (Moe; a-c) and irrigated (Wynyard; d-e) case study dairy farms under historical and future climates. Left, center and right columns show growth rates for the baseline farm, and the simplification and intensification adaptations, respectively.

In order to maintain cow liveweight and milk production due to reduced pasture growth in 2040, the need to conserve dry fodder increased. Under future climates hay/silage conservation at the dryland site increased by 45%, 21% or 16% in the baseline, simplify and intensify cases, respectively, indicating that both adaptations

Table 2. Biophysical results simulated using historical and future (2040) climate data. Values are 38 year averages for baseline management and for adaptations that simplified or intensified each baseline system.

	Baseline		**Simplify**		**Intensify**	
Dryland farm (Moe, Vic)	**Historical**	**2040**	**Historical**	**2040**	**Historical**	**2040**
Milk production per animal (kg MS^{A}/cow)	395	392	449	448	531	515
Milk production whole farm (kg MS/farm)	139,128	138,095	89,705	89,591	265,747	257,721
Grazed pasture consumed (t DM^{B}/cow)	2.8	2.3	3.7	3.4	2.2	1.9
Milking area pasture consumed (t DM/ha)	9.0	8.1	7.8	7.8	9.7	8.6
Grain consumed per animal (t DM/cow)	1.1	1.1	0.5	0.5	2.0	2.0
Grain purchased (t DM/farm)	360	360	100	100	1,000	1,000
Hay/silage purchased (t DM/farm)	240	296	25	14	985	1,037
Hay/silage conserved (t DM/farm)	290	421	344	417	237	275
Irrigated farm (Wynyard, Tas)						
Milk production per animal (kg MS/cow)	496	489	442	434	540	531
Milk production whole farm (kg MS/farm)	223,113	220,205	154,545	152,074	323,752	318,340
Grazed pasture consumed (t DM/cow)	3.6	3.5	3.6	3.5	3.3	3.2
Milking area pasture consumed (t DM/ha)	12.4	12.1	11.2	10.9	13.6	13.2
Grain consumed per animal (t DM/cow)	1.1	1.1	0.5	0.5	1.4	1.4
Grain purchased (t DM/farm)	473	473	158	158	810	810
Hay/silage purchased (t DM/farm)	239	337	124	253	853	877
Hay/silage conserved (t DM/farm)	250	236	425	412	74	75

^{A}Milk solids; ^{B}Dry matter

reduced the ability to conserve home-grown feed under climate change. The need to purchase hay/silage in future climates increased in the baseline and intensification scenarios by 52-56 t DM/year, whereas there was little need to purchase dry fodder under 2040 climates in the simplification scenario.

Influence of climate change on pasture consumption and purchased feed at the irrigated site
Pasture consumption in 2040 at the irrigated site dropped by 2-3% regardless of adaptation scenario due to 6% greater irrigation requirement (Table 2). The impact of climate change on hay/silage conservation under baseline management at the irrigated site was small but increased the need to purchase dry fodder by 41% or 104% for the baseline and simplification scenarios, respectively (Table 2).

Discussion

The goal of this study was to determine whether simplification or intensification of current management and inputs on real dairy farms would serve as a more effective adaptation to climate change. Results indicate that the outcome depends on both the metric used to assess effectiveness as well as whether farms were rainfed or irrigated. If the metric used to assess effectiveness was seasonal pasture growth rates averaged over the longer term, then neither adaptation was more effective, since both simplification or intensification differed little from baseline management (Fig. 1). However, if the metric used to assess effectiveness was annual pasture production or livestock pasture consumption, then at dryland sites adaptations that simplified farming by reducing purchase of hay and silage, stocking rates and pasture inputs appeared the most prospective option. In 2040, annual pasture production on the dryland farm under the simplified adaptation was similar to that produced historically, whereas consumption and pasture production for either the baseline or the intensified adaptation was reduced by around 10%. In contrast to the dryland farm, climate change had relatively small influence on annual pasture production, grazed pasture consumption or conservation of hay/silage on the irrigated farm, irrespective of whether the farm was under baseline management or was adapted by simplification or intensification. If effectiveness was gauged by the ability of an adaptation to alleviate the need to purchase hay, then farming intensification would appear to be the most beneficial option.

This study is currently in progress and has not yet assessed economic aspects, which from an enterprise perspective is likely to be one of the most important issues in assessing effectiveness of different adaptations to climate change. Further, we have not yet quantified risk associated with production or cash flows, which would likely differ across adaptations given that the intensification system assumed significant capital investment in major machinery and equipment.

Conclusions

Climate change reduced pasture availability and increased the need to purchase hay on the dryland farm under adaptations that intensified production; in contrast, adaptations that simplified dryland farm inputs and management were less vulnerable to climate change. Climate change had little influence on pasture production on the irrigated farm, other than a small increase in the irrigation requirement, though simplification increased the need to purchase hay. This study suggests that the most effective adaptations to climate change are farm system simplification of dryland farms and intensification of irrigated farms. Future work should consider economic implications of different adaptations such as silvopasture, which has proven more productive and more profitable than baseline systems for both dairy and beef production systems (Agri Benchmark 2015; Harrison *et al*. 2015b).

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