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Effect of inter-annual variability in pasture growth and irrigation response on farm productivity and profitability based on biophysical and farm systems modelling

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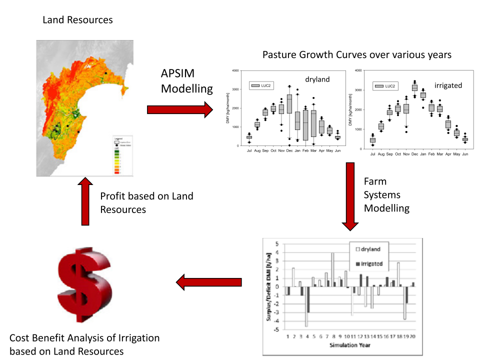
HIGHLIGHTS

- Biophysical modelling provided pasture growth curves for different fertility soils
- Inter-annual variability in pasture yield was high but decreased with irrigation
- Irrigation increased income depending on soil fertility by $525 to 883/ha.
- Average income from irrigation was 10 to >20% higher compared to individual years.

GRAPHICAL ABSTRACT



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ABSTRACT

Farm system and nutrient budget models are increasingly being used in analysis to inform on farm decision making and evaluate land use policy options at regional scales. These analyses are generally based on the use of average annual pasture yields. In New Zealand (NZ), like in many countries, there is considerable inter-annual variation in pasture growth rates, due to climate. In this study a modelling approach was used to (i) include inter-annual variability as an integral part of the analysis and (ii) test the approach in an economic analysis of irrigation in a case study within the Hawkes Bay Region of New Zealand.

The Agricultural Production Systems Simulator (APSIM) was used to generate pasture dry matter yields (DMY) for 20 different years and under both dryland and irrigation. The generated DMY were linked to outputs from farm-scale modelling for both Sheep and Beef Systems (Farmaxx Pro) and Dairy Systems (Farmax® Dairy Pro) to calculate farm production over 20 different years. Variation in DMY and associated livestock production due to inter-annual variation in climate was large, with a coefficient of variations up to 20%. Irrigation decreased this inter-annual variation. On average irrigation, with unlimited available water, increased income by $831 to 1195/ha, but when irrigation was limited to 250 mm/ha/year income only increased by $525 to 883/ha. Using pasture responses in individual years to capturing the inter-annual variation, rather than the pasture response averaged over 20 years resulted in lower financial benefits. In the case study income from irrigation based on an average year were 10 to >20% higher compared with those obtained from individual years.

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1. Introduction

In New Zealand pastoral farming systems are based on year round in situ grazing of pastures by animals, with herbage from pastures commonly comprising 85–100% of the total diet (Thorrold and Doyle, 2007). Profitability is therefore closely linked to the amount of pasture dry matter (DM) grown and utilised on-farm. In many regions of New Zealand and Australia, there is substantial variability in the pasture growth rates not just within years (seasonal variation), but also between years (Chapman et al., 2009). The latter inter-annual variation stems from variation between years in rainfall and other climatic factors that influence plant growth, including soil and ambient temperature and the number of frost days. Building the capacity to include inter-annual variability into decision making for profit maximisation and risk minimisation is a constant challenge to pastoral farmers. Studies have shown that risk management is a major factor in the decision-making processes (Makeham and Malcolm, 1993), with many farmers adopting risk minimization when considering options for changes to management practices (Chapman et al., 2008).

In the drier climate zones of New Zealand, irrigation has dramatically increased production on dairy farms. Studies in Canterbury have shown that irrigation can double the pasture yield compared to non-irrigated land (Thorrold et al., 2004), enabling intensification of farm systems or land use change to higher value such as dairying. Irrigation in such summer dry environments has increased pasture growth in the summer months, leading to reduced inter-annual variability and risk from climate variation. However, the capital investment in irrigation infrastructure and associated operating costs exposes the farmer to a higher financial risk. For irrigation to be economic, the increase in production must be sufficient to create enough additional income to cover the costs of irrigation installation as well as any other costs, including principle and interest repayments, water consent costs, and variable costs associated with irrigation usage, including electricity and labour. Irrigation has been estimated to increase the revenue from dairying in the Hawkes Bay region from $3132/ha (dryland) to $4425/ha. With increased costs from $1725/ha (for direct and fixed costs) to $2035/ha the net gain has been estimated at $992/ha before tax (MAF, 2004).

Farm system models are widely used to evaluate the influence of the impact of changes in inputs, and practices on on-farm production, profitability and environmental impacts. Such models include DairyNZ's Whole Farm Model (Berntsen et al., 2003; Vogeler et al., 2012), DairyMod (Johnson et al., 2008), DairyWise (Schils et al., 2007), Fasset (Berntsen et al., 2003; Beukes et al., 2008), Farmax® Pro (White et al., 2010), Farmax® Dairy Pro (Bryant et al., 2010) INFORM (Rendel et al., 2013), and the Moorepark Dairy Systems Model (MDSM) (Shalloo et al., 2004). The two Farmax (www.farmax.co.nz) models are whole-farm decision support models that use monthly estimates of pasture growth and farm and livestock information to determine the production outcomes of managerial decisions.

Most analyses of the economics of irrigation are limited to the impact of irrigation on pasture growth and farm profitability in an average rainfall year. Although seemingly adequate for climates which have predictable soil moisture deficits each summer, in areas where soil moisture deficit varies from year to year, cost-benefit and investment analyses need to consider inter-annual variation. Based on a farm study Fariña et al. (2013) used an integrated modelling approach to assess the effect of inter-annual variation in irrigation water and pasture and crop yield, among other factors, on operating profit of a dairy farm in Australia. They used DairyMod and APSIM (Agricultural Production Systems Simulator) to simulate pasture and crop growth over 100 climate years to capture the actual impact of climate variation on pasture and crop growth for a dairy farm. In a previous study we linked the APSIM model with land resource information to obtain spatially discrete estimates of seasonal pasture growth patterns, including inter-annual variation, across three different regions of New Zealand (Vogeler et al., 2016a). When such pasture growth data is linked with farm systems modelling and land resource information, the impact of on-farm changes in forage supply on animal policies and farm production can be explored at a regional scale (Vogeler et al., 2014).

In this study we evaluate the benefits of irrigation as a strategy for reducing inter-annual variability in pasture growth and farm production and profitability using an integrated modelling approach based on soil, land use and farm data from central Hawkes Bay, located on the East Coast of the North Island of New Zealand. The area is largely influenced by summer dry environments, and large scale irrigation is a foreseeable option. APSIM and Farmax (Farmax® Pro and Farmax® Dairy Pro) were used to model the alternatives. The AgPasture module within APSIM has been tested against experimental pasture growth data from a wide range of New Zealand climates (Li et al., 2011; Vogeler et al., 2016a), as well as for capturing management effects on pasture growth (Vogeler et al., 2016b). The model was used to obtain pasture growth rates for soils of different fertility and under different management regimes (± fertilisation; ± irrigation). To reveal inter-annual variation in pasture growth the model was run for each of the different scenario for 20 consecutive years. The two Farmax models are widely used within New Zealand and have been set up and used to evaluate different farming systems across NZ including Hawkes Bay (Bryant et al., White et al., 2010; Vibart et al., 2015; Lieffering et al., 2012). The models were used to generate estimates of farm profitability for different representative sheep and beef farming (S&B) and dairy systems within the Hawkes Bay region.

Environmental impacts of irrigation and farm intensification with higher inputs of fertiliser, need to be considered in any regional benefit analysis, but are beyond the scope of this paper. Possible impacts include increases in the risk of N loss to the environment with increased amount of N cycling in the soil/plant/animal system in intensively managed pasture systems (Hatch et al., 2002), increased risk of run off (McDowell and Nash, 2012) and availability of water and implications for water storage and river levels (Cullen et al., 2006).

The objectives of the paper are to assess, at the regional scale:

1. the influence of inter-annual variation in climate on pasture growth and associated livestock production of S&B and dairy farm systems under three different management intensities
2. the pasture response to irrigation and associated lift in livestock production and farm income for dairy systems based on either unlimited supply of water, or irrigation water limited to the average annual amount required
3. the benefits and economics of irrigation for dairy systems using either long-term average pasture responses to irrigation or pasture response to irrigation in a number of individual years and its flow-on effects on the farm system.

2. Methods

2.1. Case region

The Hawkes Bay region is situated on the eastern side of the North Island of New Zealand, and comprises a land area of about 1.4 million hectares, mostly of rolling hill country (Fig. 1). Rainfall in the area is closely related to elevation, ranging from <800 mm to over 2000 mm per year. Of this about 30% occurs in the winter months (June to August), with frequent droughts in spring and summer (Chappell, 2016).

On the Ruataniwha Plains, within the central Hawkes Bay, a water storage and irrigation scheme has been proposed to provide water to lift the performance of existing agricultural systems and create options for new enterprises, all of which would add to the local and regional economy. The area on the plains that could potentially be covered by the irrigation is about 30,000 ha. The area is currently predominantly under pastoral farming, based on information held in AgriBase™ (AsureQuality, 2010), a spatial database of New Zealand farms. Of this