Performance of Dryland Agricultural Systems under Future Climate Change in the Lower Murray Region

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EXTENDED ABSTRACT

Dryland agriculture in the Lower Murray Region of Australia occupies the largest land area, drives regional economy and impacts on biophysical systems. The predicted future warming and drying scenarios in southern Australia have the potential to threaten current agricultural and environmental systems. In this paper we assess the impact of possible future climate change on the productivity and environmental performance of agricultural systems of the Lower Murray region (Figure 1) in southern Australia.

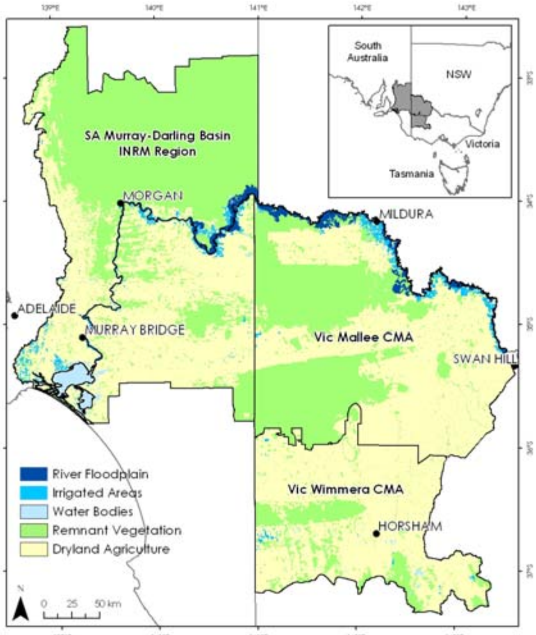

Figure 1. Location map and land use in Lower Murray region in southern Australia.

Of the existing farming systems, the crop/pasture rotation system is by far the most common and is examined here. Soil profile data was obtained for 14 broad soil types by overlaying representative measurement points with each of the soil classes. Sixteen climate zones were classified using multivariate cluster analysis. A farming systems model was used to simulate the performance of the farming system under traditional farming practices under historical climate and four future climate change scenarios (Table 1).

Table 1. Definition of climate change scenarios

Scenarios	**Definition**
S1 – Mild Warming/Drying	1°C warming and 5% drying, at 420 ppm CO_2 expected around 2020 with high fossil fuel use (A2 SRES)
S2 – Moderate Warming/Drying	2°C warming and 10% drying, at 550 ppm CO_2 expected around 2050 (A2 SRES)
S3 – Severe Warming/Drying	4°C warming and 25% drying, at 750 ppm CO_2 expected around 2100 (A2 SRES)
S4 – Mild Warming/Wetting	1°C warming and 5% wetting, at 420 ppm CO_2, to show a possible, but unlikely scenario around 2020

Under the current climate, the simulated wheat grain yield ranged from <500kg/ha to >3,000kg/ha and annual pasture productivity ranged from 2,000 to 6,000kg/ha from north to south. Deep drainage under the dryland farming systems was simulated to have a range from negligible to above 150mm/year..Deep drainage rates greater than 10mm/year only occurred in the southern part of the region. Future warming and drying scenarios were predicted to reduce crop yields and pasture productivity by up to 40%. In terms of the environmental effects, deep drainage was reduced by up to 70% under farming systems, leading to a substantially reduced risk of dryland salinisation. Conversely, wind erosion risk was enhanced by up to 20% through reduced biomass productivity and the increased exposure of soils.

1. INTRODUCTION

The social and economic foundations of the Lower Murray region in southern Australia are founded on agriculture. A diverse range of agriculture occurs in the region ranging from dryland cereal cropping and grazing, to intensive, irrigated production of fruit, grapes, and dairy. Dryland agriculture occupies the largest area. Innovative management is required to address the ongoing degradation of biological, land and water resources within the economic and social context. Assessment of the productivity and environmental performance of dryland agricultural systems under future climate forms part of the Lower Murray Landscapes Futures (LMLF) project, which aims to assess the impact of existing natural resource management (NRM) plans and the impact of these plans under alternative landscape scenarios.

Studies have been carried out including sites in Lower Murray to investigate the impact of climate change on crop productivity and water balance (Howden et al, 1999a,b; Luo et al., 2003, 2005a,b). Luo et al (2005a) predicted that median wheat grain yield would decrease across all locations from 13.5 to 32% under the most likely climate change scenarios. The spatial analysis in the Mid-Lower North of South Australia by Luo et al (2005b) indicated the necessity of including spatial distribution of soil properties in impact assessment due to the spatial variability found for projected impact outcomes within climate divisions. To date, there is still no detailed regional assessment of climate change impact, which considers the spatial variability of soils and climate for this region.

This paper presents a study of the productivity and environmental performance of a typical dryland farming system as affected by current and future climate across the Lower Murray Region of Australia. We explicitly consider the impact of the spatial variation of soils on both productivity and water balance of the farming systems.

2. MATERIALS AND METHODS

2.1. Study Area

The Lower Murray study area (Figure 1) covers the South Australian Murray Darling Basin Natural Resource Management region, the Victorian Mallee Catchment Management Authority region, and the Victorian Wimmera Catchment Management Authority region.

2.2. The Agricultural Systems Model – APSIM

The farming systems model APSIM (Keating et al., 2003) was used to simulate the performance of dryland farming systems. APSIM simulates biophysical process in farming systems at a daily time step. It allows the evaluation of management intervention through tillage, irrigation, or fertilisation as well as choice, timing and sequencing of crops either in fixed or flexible rotations. It has been widely validated and used in Australia (Keating et al., 2003). APSIM 4.2 is used in this study.

2.3. Soil and Climate Data

Soil profile data for the study area has been assembled from several sources. The Department of Primary Industries and Resources of South Australia provided a list of soil profile data in South Australia and a few in Victoria (Maschmedt, 2006, unpublished data). Primary Industries Research Victoria provided several other soil profile data in Victoria (Fawcett, 2006, unpublished data). In addition, data from a number of soils pits (Victorian DPI Werribee, 2006, unpublished data) was also assembled. These points were overlaid with the broad soil classes and the data visualised and compared. The plant available water holding capacity (PAWC) of these soil profiles was then compared within each broad soil class by graphing the drained upper limit and lower limit at 15 bar suction. PAWC is a key soil parameter affecting crop growth and deep drainage. Data points that are representative of the broad soil classes were then selected for input into APSIM. All together, 14 soil profile types were derived. For each soil layer, only the soil texture, bulk density, pH, organic carbon, drained upper and lower limits are available. Other parameters required by APSIM are estimated based on the current available information.

Across the study region, 16 climate zones were classified using multivariate *k*-means cluster analysis and maximum likelihood classification. A representative climate station was selected within each of the 16 climate zones. Historical climate records from 1889 to 2005 were obtained from SILO patched point climate database

2.4. Regionalisation of Modelling

To simulate agricultural production systems over the entire Lower Murray study area, a process of geographic regionalisation was adopted. The study area is regionalised into homogeneous soil/climate regions by combining the broad soil class map with the climate zones map. Each unique combination of soil class and climate zone is representative of a particular soil and climate type. Soil information is attached from the broad soil class of the APSIM zone and climate information is attached from the climate station relevant to the respective climate zone. A total of 138 unique APSIM zones were created through this process which enables us to simulate the spatial distribution of the impacts of climate change on agricultural production and environmental systems at a relatively high resolution.

2.5. Representative Farming Systems

Farming systems in the Lower Murray vary from continuous cropping to grazing and may include many variations of cropping grazing rotation. Wheat is the most common crop. Most farmers rotate their crops over a number of years to protect the crop from disease, to manage weeds including reducing herbicide resistance, to provide diversification, and to respond to economic opportunities. In most cases farmers will sow a non cereal crop such as canola (an oilseed), lupins, field peas, chickpeas, or pulse crops in their rotation. Given that many of the farmers in the northern parts of the study area will not be able to grow higher value non-cereal crops due to low rainfalls, lupins is used as an analogue for the rotation crops. In higher rainfall areas, lupins will have a much higher productivity thereby partially accounting for the fact that higher rainfall farmers may, in reality, rotate a higher value crop such as canola.

The cropping/grazing rotation was considered representative of farming systems within the study area and is defined as a rotation of wheat/pasture/lupins/pasture, all in one year phase.

For wheat crops, the sowing window was assumed to be between 1 June and 31 July each year. The wheat cultivar 'Janz' was sown at a plant density of 100 plants/m^2 with a sowing depth of 4cm when total rainfall in 10 consecutive days reached 25 mm or when the end of the window was reached.

For lupins, the sowing window was assumed to be between 1 May and 31 July each year. The lupins cultivar 'Belara' was sown at a plant density of 25 plants/m^2 with the same sowing depth and rainfall condition as for wheat.

For annual pasture, APSIM-Weed was used to simulate the growth of a late maturing winter grass to mimic the pasture phase. The sowing window, density and depth are the same as for wheat.

To isolate the effects of climate and water holding capacity of soils, it was assumed that nitrogen supply was sufficient to meet the crop demand, so no nitrogen deficiency was simulated.

Traditional land management options are characterised by the fallow period of the cropping cycle and the way soil is treated during that fallow period. In particular, at harvest, the crop was cut at 50 mm height from soil surface and 95% of the cut straw biomass was baled and removed from the system. The remaining crop stubble was incorporated into the soil by tillage in February and three further times before sowing of the next crop. One till was done after each pasture phase, just before sowing of the following crop.

2.6. Climate Change Scenarios

This study takes a scenario analysis approach whereby future scenarios are used to assist with strategic planning. For this exercise we used 4 possible future climate change scenarios (Table 1) in addition to the baseline (current) climate.

Baseline climate data extracted from the SILO database was modified according to the level of variation expressed in each climate change scenario. APSIM was used to model the expected outcomes under each climate scenario using the new climate scenario datasets. For all climate scenarios, all land management, farming systems and crop types were held constant to ensure that only the effects of climate change were expressed.

2.7. Wind Erosion Modelling

APSIM4.2 does not simulate wind erosion of soils. Detailed modelling of wind erosion involves solving the mass transport equation and requires detailed wind, rainfall and soil data (Fryear et al, 1998). The objective of this study was to compare the relative impact of climate change scenarios on wind erosion. Therefore, a very simple approach was used, which is based on the findings that a good relationship exists between the relative soil loss and the fraction of soil surface covered by crops and crop residues (Gregory, 1984; Fryrear,1985; Horning et al, 1998; Fryrear et al, 1998). When results are expressed in terms of the percentage ground cover, differences between residues are small. The size or type of the non-erodible material to cover the soil does not significantly influence the reduction in soil loss (Fryrear, 1985).

Relative soil loss (RSL) is defined as the ratio of soil eroded for a given treatment divided by the maximum soil loss from a bare, smooth soil surface (Horning et al, 1998). For the current purpose of comparing the relative impact of different climate change scenarios on wind erosion, the biggest changes between farming systems will be the surface cover, so that it is reasonable to assume that all other factors are the same except for the impact of surface cover including standing and flat residue cover and crop cover. Because APSIM 4.2 can not simulate the difference between standing and flat residue, all residues were treated as flat residue. *RSL* was calculated monthly as follows based on the residue (R_C) and crop (C_C) cover from APSIM:

$$RSL = \exp(-4.38R_C) \times \exp(-5.614C_C^{0.7366})$$

The relative soil loss is primarily a function of soil exposure and can be considered as a wind erosion factor score. Precise wind measurements are not available in long term historical climate data and hence calculation of the actual soil erosion in tonnes per hectare was not possible. To determine a long term average annual wind erosion score for each unique APSIM Zone, monthly factor scores were averaged for each year, and yearly scores averaged over the 115 simulation years.

3. RESULTS AND DISCUSSIONS

3.1. Farming System Productivity

The simulated crop yield for traditional farming practices is shown in Figure 2. Under the baseline scenario (S0 in Figure 2), average wheat yield ranged from 500kg/ha in the north part of the region to above 3,000kg/ha in the south and southeast areas, responding to the increasing annual rainfall. The simulated yield of lupins ranged from less than 300kg/ha in the north to around 2,000kg/ha in the south and southeast. The productivity of annual pasture under gazing ranged from <2,500kg/ha to 6,000kg/ha of dry matter (Figure 2, S0).

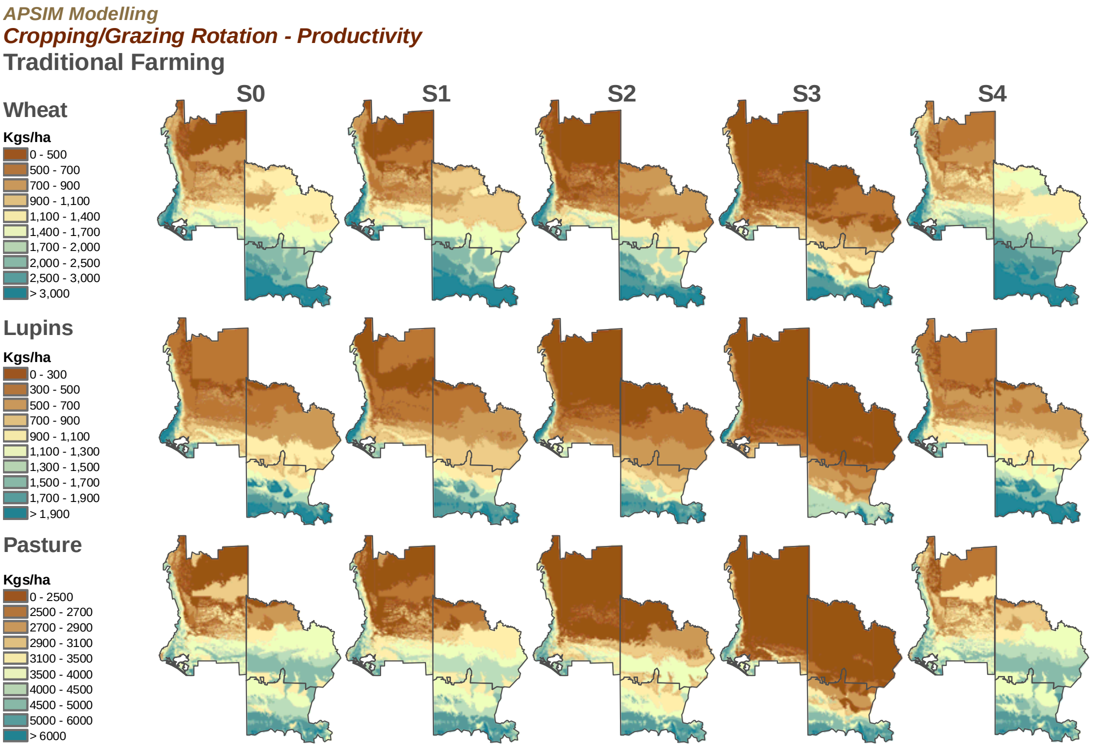

Figure 2. Simulated crop/pasture productivity under the baseline and four climate change scenarios

The mild (S1) warming/drying scenario led to a slight reduction in crop yield/biomass production with lupins being the worst affected with a 5% reduction in yield whilst for wheat and pasture the reduction was less than 2% (Figure 3, S1). Yield and productivity losses were higher in the moderate warming/drying scenario (S2) with a 10% reduction in wheat yield and a 21% reduction in lupins yield. A substantial decrease in yield was simulated under the severe warming/drying scenario (S3), with 25% and 41% lower yields for lupins and wheat, respectively (Fig 3, S2,S3). This equates to actual yields of less than 1,000kg/ha for lupins in over 80% of the region and wheat yields less than 1,100kg/ha over more than half of the region (Fig 2, S3). A similar impact pattern was also simulated on annual pastures (Figure 2). It seems that more than 2°C warming and 10% drying would have significant negative impact on crop and pasture productivity in most parts of the region except in the southernmost higher rainfall areas. The mild warming/wetting scenario was simulated to increase crop productivity. Despite having similar rates of decline in productivity in the warming and drying scenarios, wheat and pasture exhibited distinctly different trends in the warming/wetting scenario. Wheat responded twice as well as pasture to the S4 scenario whilst lupins (the most severely affected crop in the drying scenarios) showed a smaller positive response to the wetter climate change. The simulated decline in wheat yield is consistent with the findings of Luo et al. (2005a).

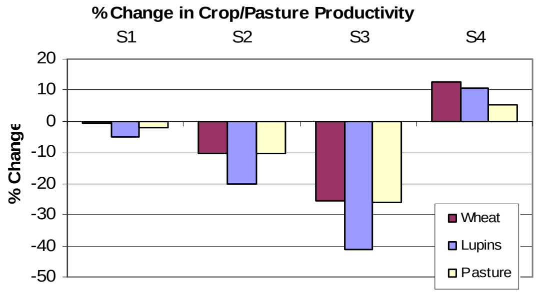

Figure 3. Percentage change in crop/pasture productivity under climate change

3.2. Deep Drainage

The decreasing annual rainfall and increased evapotranspiration over the climate change scenarios left significantly less water available for deep drainage. Under the baseline scenario, the mean annual deep drainage under the cropping/grazing rotation system ranged from negligible in the mid-north region to above 150mm/year in the upper Wimmera (Fig 4). The spatial distribution of deep drainage, although similar, did not directly correlate with that of rainfall, reflecting the significant impact of soil water holding capacity and surface runoff.

Increased warming and drying would lead to reduced deep drainage. Simulations suggest that currently, around half of the region has an annual deep drainage of >10mm/year under the cropping/grazing rotation system. Under the warming and drying scenarios S1, S2 and S3, more than 65%, 85%, and 95% of the region, respectively, would have mean annual deep drainage of <10mm/year (Fig 4). The scenarios S1, S2, and S3 resulted in significant reductions in deep drainage of up to 20% in S1, 45% in S2, and 70% in S3 respectively (Fig 5). Interestingly, unlike crop/pasture productivity the effects of climate change on deep drainage appeared to have similar impacts on the wheat, lupins, and pasture phases. Howden et al (1999b) also simulated reduction in drainage in Queensland and Western Australia under mid-range climate change scenarios. As would be expected, the mild warming/wetting scenario was simulated to increase deep drainage across the region (Figure 5). The increase in deep drainage under the mild warming and wetting scenario was tempered by increased evapotranspiration by crops and pasture.

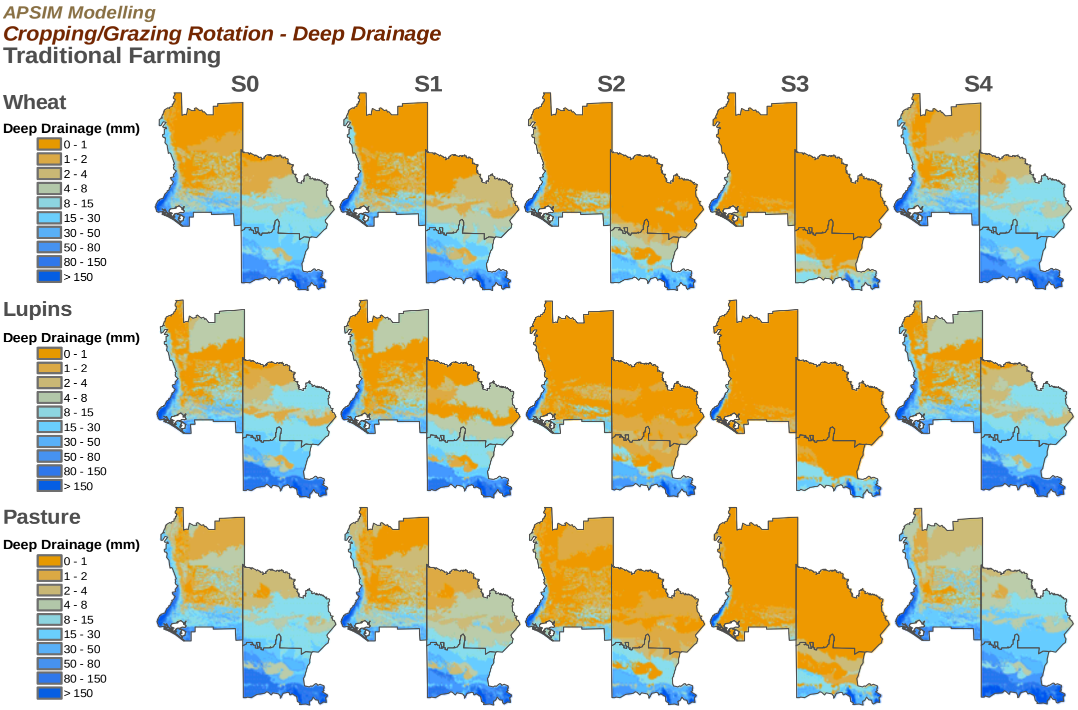

Figure 4. Simulated deep drainage under the baseline and four climate change scenarios

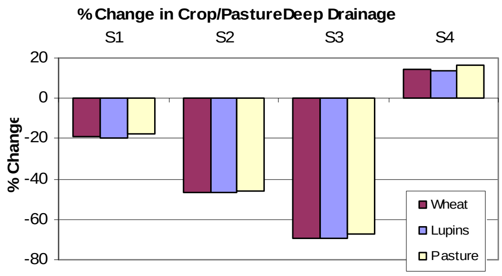

Figure 5. Percentage change in crop/pasture deep drainage under climate change

3.3. Wind Erosion

Future warming and drying scenarios were simulated to increase wind erosion across the region (Fig 6). Although the percentage change in wind erosion across scenarios was not as pronounced as the impacts on productivity or deep drainage.

Simulations showed substantially higher wind erosion factor scores in the northern, drier parts of the study area (Fig 7). Inspection of the spatial distribution of the wind erosion factors scores revealed the significant influence of soil structure/type. The soil effect was most clearly evident in the baseline and S1 scenarios. Despite higher annual rainfall, many of the lighter sandier soils in the Mallee and central SAMDB exhibited higher wind erosion factor scores than the drier areas in the north. This was reflected by the model through impact of the soils on the crop/pasture performance. In addition to being the most exposed, these soils were also the most susceptible to wind erosion due to their sandy texture. Wheat crops generally provided greater protection for the soils than lupins or annual pasture in all scenarios.

The mild warming/wetting scenario was simulated to reduce wind erosion probability slightly for lupins and annual pasture. However the impact of the S4 scenario on wind erosion under wheat showed significantly greater reductions in wind erosion (Fig 6). This may be due to the greater increase in wheat productivity under this scenario, leading to more increased crop cover (Fig 3).

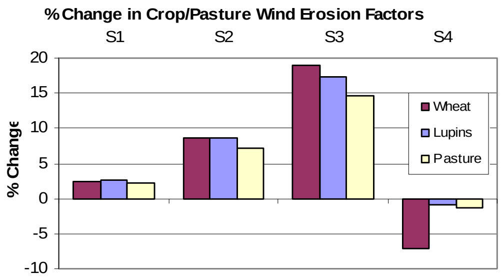

Figure 6. Percentage change in crop/pasture wind erosion under climate change

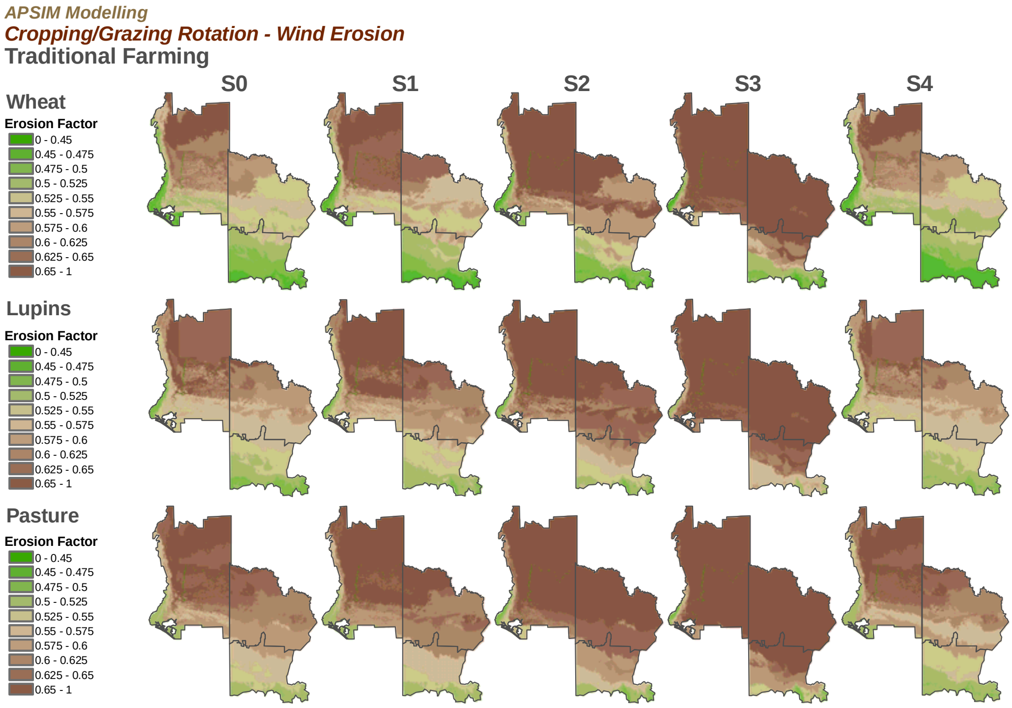

Figure 7. Simulated wind erosion score under the baseline and four climate change scenarios

4. CONCLUSION

The simulation results in this paper reflect the combined impact of spatial variation of soils and climate on the productivity and environmental performance of dryland farming systems in the Lower Murray Region. The spatial pattern of simulated crop yield generally followed the spatial distribution of rainfall and soils.

Under the current climate, mean wheat grain yield in the dryland farming system was simulated to be below 1,000kg/ha in the northern and above this level in the southern part of the region. Simulated wheat yields were greater in the higher rainfall area of the Mt Lofty Ranges along the western edge of the study area. The lupins yield was simulated to be less than 1,000kg/ha in most parts of the region, except in the south west and southern higher rainfall areas. Simulated annual pasture productivity ranged from 2,000 to 6,000kg/ha from north to south. Deep drainage under dryland farming systems was simulated to range from negligible to above 150mm/year under the baseline. Less than 10mm/year of drainage occurred in the northern part of the region.

Future warming and drying climate change scenarios were estimated to lead to a decrease in crop and pasture production up to 41%. Wind erosion risk was also simulated to increase by around 20% under farming system rotations. Conversely, however, a reduction in deep drainage of up to 70% could be expected from dryland farming systems leading to a substantially decreased risk of dryland salinisation. A future warming and wetting scenario is likely to have a positive net effect on crop production with a slight increase in deep drainage and slight reduction in wind erosion across the region.

5. ACKNOWLEDGEMENTS

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