THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON PASTURE AND CATTLE PRODUCTION IN MONGOLIA

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Abstract. The objective of this study was to assess the impact of climate change on plant and livestock production in several natural regions of Mongolia. The Simulation of Production and Utilization of Rangelands model was used for the assessment of the climate impacts. Long-term (1961-1990) climatic data and biophysical and physiological parameters of pasture grassland and cattle were used in the study. The selection of simulation sites for the study was based on regions where there are many cattle. Climate change scenario data were obtained by combining historical weather data from each site with predicted output from general circulation models. Results from baseline runs were compared with four climate change scenarios and a scenario with baseline climate conditions and doubled carbon dioxide ($2\times CO_2$). The impact of climate change on pasture production is estimated to be negative in the Gobi desert area and favorable in colder regions. Livestock intake and livestock weight are estimated to generally decline in late summer when digestibility is lower. Average daily weight gain of Mongolian steers that have only pasture forage is estimated to be lower, whereas it is estimated that there will be no negative effects on the weight gain of steer that are provided supplemental feed.

Key words: Mongolia, grasslands/livestock, cattle production, pasture production, CCCM, GFDL, GISS, SPUR2, UKMO

1. Introduction

Average rates of carbon dioxide (CO_2) increase during the 1980s were 0.4% or 1.5 ppm per year (IPCC, 1995). Predictions from general circulation models (GCMs) indicate that with a doubling of atmospheric carbon dioxide, the average global temperature may rise by 1.5 to 4.5°C (IPCC, 1995). Changes in global climate, as predicted by the GCMs, could have profound implications for agriculture production worldwide, and for rangeland production and animal husbandry in Mongolia.

The Mongolian economy relies heavily on livestock production. Products such as meat, butter, wool and hair, and hides and furs account for one half the country's output and almost 90% of its exports. The pastures that support livestock are strongly affected by climate and weather conditions, so, ultimately, climate affects the economic condition of the country. In Mongolia there are many different types of pasture and, within these types, different amounts of standing biomass. Pasture production is unstable from year to year, and in some years it is quite low because of prolonged dry and warm weather during the growing season. The mean of peak standing biomass varies from 100 to 1,000 kg ha^{-1}, and decreases from north to south in Mongolia, depending on the features of the regions. In the north part of the country, there are high mountains and partially wooded steppe, in the east and southeast is steppe, and in the south is the Gobi Desert. Because cattle and pasture production are economically important to Mongolia, the potential effects of climate change on production is an important issue to study. The study of the vulnerability of cattle and pasture production to potential climate change is also important for future policy development.

Research has been conducted to examine the response of rangeland ecosystems to greenhouse warming. For example, Baker *et al.* (1993) used the Simulation of Production and Utilization of Rangelands (SPUR2) enhanced model, developed by the USDA-ARS Great Plain Systems

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Research Unit and Colorado State University, to examine the potential effects of climate change on ecosystem processes and cattle production on U.S. rangelands. This model was used in the study presented here.

The objective of the study described here was to assess the impacts of potential climate change under several different climate change scenarios on rangeland production and beef cattle in Mongolia using SPUR2.

2. Methods

The SPUR2 model (Hanson *et al.*, 1992), an enhanced version of SPUR (Wight and Skiles, 1987), is a general grassland ecosystem model that simulates the cycling of carbon and nitrogen through several components, including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. Competition between plant species and the impact of grazing on vegetation are also simulated. SPUR2 has been modified to simulate the direct effects of CO_2 on plant production. SPUR2 also contains herd-wide, life-cycle beef cattle production and steer simulation models.

Ten sites that represent five different natural regions were selected for the simulations of rangeland and cattle production of Mongolia (Figure 1, Table I).

The five functional groups simulated by the model include warm and cool season grasses, warm and cool season forbs, and shrubs. Julian dates for the beginning of seed production and

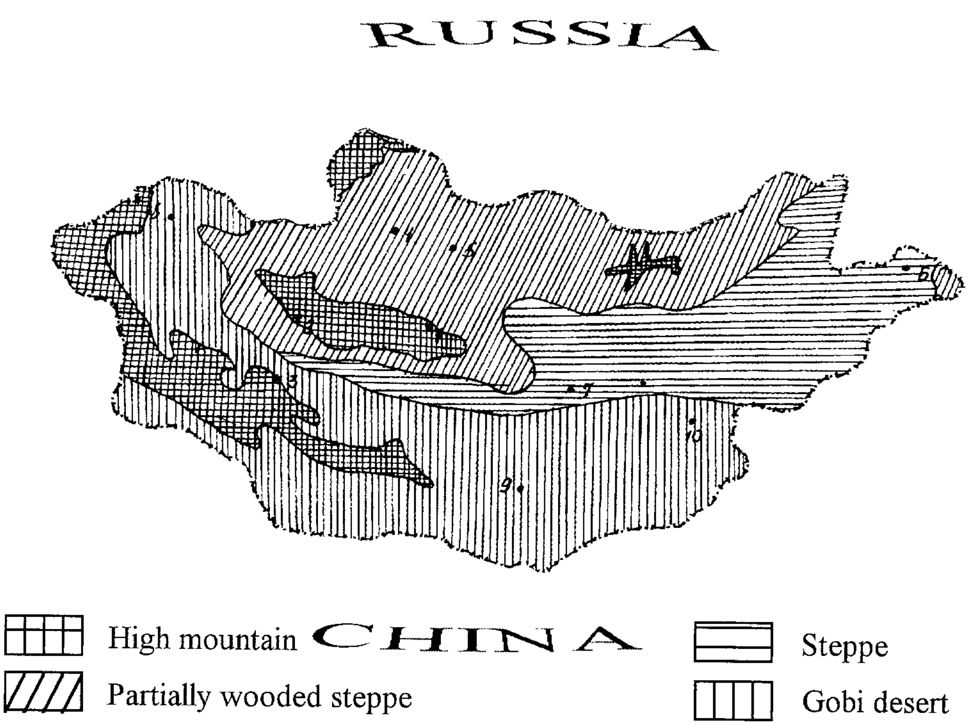


Fig. 1. Natural zones of Mongolia and site locations (site names are given in Table I).

TABLE I
Characteristics of study sites

Natural Region	Map Reference	Site Name	Latitude	Longitude	Elevation (m)
High Mountain (Khangai Mountains)	1	Tsetserleg	47°27'	101°28'	1,695
	2	Uliastai	47°51'	96°51'	1,751
High Mountain (Altai Mountains)	3	Altai	46°24'	96°15'	1,751
Partially Wooded Steppe	4	Moron	49°38'	100°10'	1,288
	5	Hutag	49°23'	102°42'	938
Steppe	6	Halhgol	47°37'	118°31'	688
	7	Mandalgov	45°46'	106°17'	1,393
Gobi Desert	8	Ulaangom	49°59'	92°04'	934
	9	Dalanzadgad	43°23'	104°25'	1,469
	10	Sainshand	44°54'	110°07'	915

the beginning and end of senescence, and maximum root to shoot ratio for each functional group, were also used. Soil texture class and the representative composition of each site were obtained from the Institute of Land Use Policy.

The steer simulation model was used in this study to determine the effects of climate change on animal intake and weight for animals approximately 6-18 months old. Three steer genotypes (Selenge, Halhgol, and Mongolian) were simulated in this study. Mongolian steers are pastured in all territories of Mongolia. Selenge and Halhgol steers are primarily raised for meat production and are bred in the northern part of Mongolia where pasture plant biomass is higher. In the model, the Selenge and Halhgol genotypes are fed a 2 kg daily supplement from January to May, but no supplemental feed is provided to the Mongolian genotype. The weight parameters of steer genotypes are shown in Table II.

The SPUR2 model is driven by daily inputs of precipitation, maximum and minimum temperatures, solar radiation, and daily wind. Six climate scenarios were used in the study: a baseline scenario, a baseline climate with $2\times CO_2$ scenario, and climate change scenarios derived from four GCMs. The baseline scenario was developed using 30 years of historical climate data (1961-1990) from each simulation site. The daily maximum and minimum temperatures, precipitation, and wind speed for that period were obtained from the Climatic Data Base made available by the Hydrometeorological Research Institute. Daily solar radiation was calculated using observed daily sunshine duration. The GCM scenarios used for the climate change runs were produced by the following models: Goddard Institute for Space Studies (GISS) (Hansen *et al.*, 1983), Geophysical Fluid Dynamics Laboratory (GFDL) (Mitchell *et al.*, 1990), United Kingdom Meteorological Office (UKMO) (Wilson and Mitchell, 1987), and Canadian Climate Centre Model (CCCM) (Boer *et al.*, 1992). Additionally, a scenario that maintained current climatic variables but with a doubled atmospheric concentration of carbon dioxide was considered ($2\times CO_2$ scenario). Other researchers have found that the UKMO $1\times CO_2$ scenario results provide the closest fit to Mongolia's current climate (e.g., Bayasgalan *et al.*, 1995).

The main limitations in using the SPUR2 model are that management practices remain constant over the simulated period, therefore adaptive responses were not considered (Benioff *et al.*, in press).

TABLE II
Weight parameters of steer genotypes

Genotype	Birth Month	Birth Weight (kg)	Weight at 8 Months (kg)	Weight at 18 Months (kg)	Mature Weight (kg)
Selenge	March-May	25.0	175	275	560
Halhgol	March-May	20.5	163	253	510
Mongol	March-May	19.5	145	216	480

3. Results

The GCMs predicted various climate changes for different locations and times in Mongolia. The estimated temperature increases range from 1.7 to 12.5 °C depending on the location and the scenario, and precipitation increases range from 40 to 167%. In the mountainous north, average precipitation could increase by 8% in the growing season, but in the south precipitation averages are estimated to increase by only 2%. Consequently, the estimated effects of climate change on plant and animal production varied by month, scenario, and location.

Under the scenario of current climate conditions and doubled CO_2, the peak standing biomass did not increase greatly at the 10 sites (Table III). But when CO_2 doubling was combined with changes in temperature and precipitation, the peak standing biomass increased significantly at most study sites under most scenarios. At the sites in mountainous regions, the increase in peak biomass may be due to increased temperatures. The results show that in the Khangai mountains and in the partially wooded steppe, the peak standing biomass would increase under climate conditions estimated by the GCMs for most scenarios at most sites (Figure 2a). At Tsetserleg (Khangai mountains) and Moron (partially wooded steppe), the GFDL and GISS scenarios predicted decreases in precipitation during the growing season, so the decrease in peak standing biomass under these climate scenarios would be expected. In the cold and elevated regions of the country, climate change could prove to be favorable for rangeland production because precipitation would be higher under global warming than it is today.

TABLE III
Peak standing biomass changes under different scenarios
(as percent of current standing biomass)

Natural Region	Site Name	Actual Peak Standing Biomass (kg ha^{-1})	Simulated Peak Standing Biomass (kg ha^{-1})	Peak Standing Biomass Changes under Different Climate Scenarios				
				$2\times CO_2$	CCCM	GFDL	GISS	UKMO
High Mountain (Khangai Mountains)	Tsetserleg	590	569.4	1.5%	9.2%	-6.5%	-9.4%	2.3%
	Uliastai	260	394.1	3.3%	15.0%	3.9%	14.1%	13.3%
High Mountain (Altai Mountains)	Altai	110	189.3	4.7%	2.8%	3.1%	8.5%	3.4%
Partially Wooded Steppe	Moron	390	307.9	6.2%	310.2%	-27.0%	-39.7%	25.1%
	Hutag	330	468.1	4.6%	12.2%	7.2%	4.6%	8.7%
Steppe	Halhgol	1,110	388.5	4.2%	24.0%	-13.9%	5.6%	12.9%
	Mandalgov	240	235.5	4.8%	8.1%	3.1%	-21.3%	5.6%
Gobi Desert	Ulaangom	120	221.7	1.9%	21.5%	3.2%	-4.2%	14.2%
	Dalanzadgad	90	170.3	4.5%	8.3%	6.2%	3.9%	6.3%
	Sainshand	190	178.2	2.9%	5.4%	3.7%	-2.4%	4.5%

The south steppe region and the Gobi region of Mongolia are warmer and drier. For the sites in southern Mongolia, the UKMO predicted a drop in precipitation in the first part of the growing season, and the CCCM and GISS showed decreased rainfall in last part of growing season. At some sites in the southern part of the country, the UKMO and GISS scenarios predicted decreased rainfall throughout the growing season. Thus, generally peak standing biomass in these regions is not estimated to increase significantly; see, for example, Dalanzadgad (Figure 2b). Under the GCM scenarios, the time of peak standing biomass is simulated as 6-37 days earlier than under current conditions and the vegetative growing period is simulated as 13-49 days longer than under current climate conditions. Plant growth could start early because of precipitation and temperature increases for a short period in the spring. This result is similar to results from Hunt *et al.* (1991) and Baker *et al.* (1993), which indicated that changes in temperature increased the length of the growing season in the United States. Because of climate change, standing biomass accumulation on pastures may begin in March-April at most of sites, but from June onward, standing biomass would be close to or lower than the baseline scenario (Figure 2).

Simulated potential evapotranspiration generally increases under climate warming. For Mongolia, larger increases of potential evapotranspiration are simulated for April, May, and June. In the Gobi desert areas, potential evapotranspiration increases start from March.

Soil evaporation projections for Mongolia are different under the different GCM scenarios. The differences depend on precipitation projections and on plant cover. Available water for plants generally decreases for the entire growing season (April to October) at the study sites.

With increasing temperature, evapotranspiration and transpiration are estimated to be higher and water available to plants is estimated to be lower. The combination of these factors could have an unfavorable effect on plant growth. Because of early plant growth, estimated plant nitrogen contents were higher from March to May and lower later in the year under the climate change scenarios.

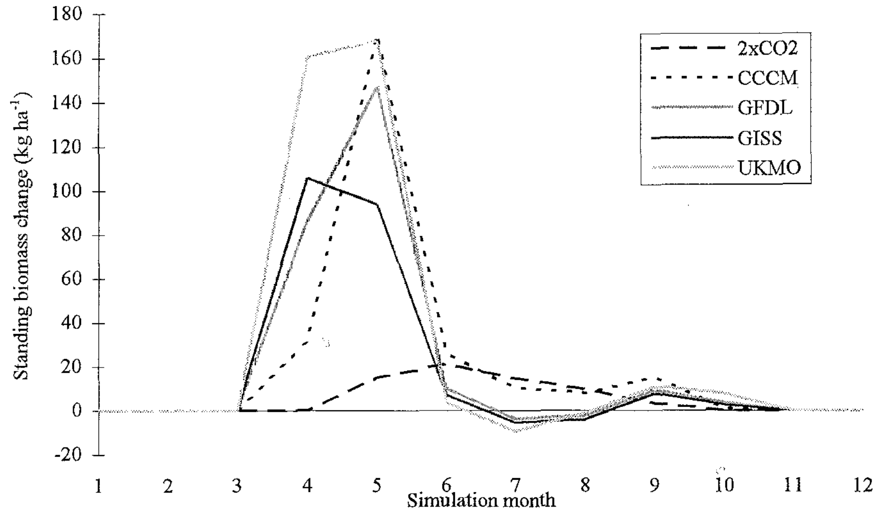
Increases in soil carbon were predicted under all GCM scenarios for sites in the northern regions; therefore, conditions would be suitable for an increase in carbon sequestration and an increase in potential nutrient storage. At the same time, decreases in soil carbon were predicted for the southern regions. Soil nitrogen deficits could increase desertification. However, in the simulations soil inorganic nitrogen did not significantly change.

The simulations also found that in the spring the simulated C:N ratio was higher than in the baseline scenario, but that after flowering the C:N ratio would potentially be decreased. The C:N ratio of the above-ground biomass is used to indicate the change in plant tissue quality. A decline in the C:N ratio may indicate lower plant quality.

Steer production generally declined under the climate change scenarios. In first period of the growing season (beginning in April) when crude protein and digestibility were greater, livestock intake was increased. During summer (June to August), temperature increased, so estimated livestock intake was decreased (Figures 3 and 4). Figure 5 is an example of intake for Mongolian steer. Intake for all genotypes was similar.

Under the current climate in Mongolia, the weight of the Mongolian genotype of steer, which graze year-round, declines in winter and spring and increases in summer and autumn (Figure 6). The simulation results showed that average daily gain decreased at Tsetserleg under the GISS, GFDL, and UKMO scenarios, and at Halhgol under the CCCM, GFDL, and $2\times CO_2$ scenarios. The simulation results also showed that average daily gain increased at Hutag under all scenarios. The study results show that meat production of the Mongolian genotype of steer could generally decline.

(a)



(b)

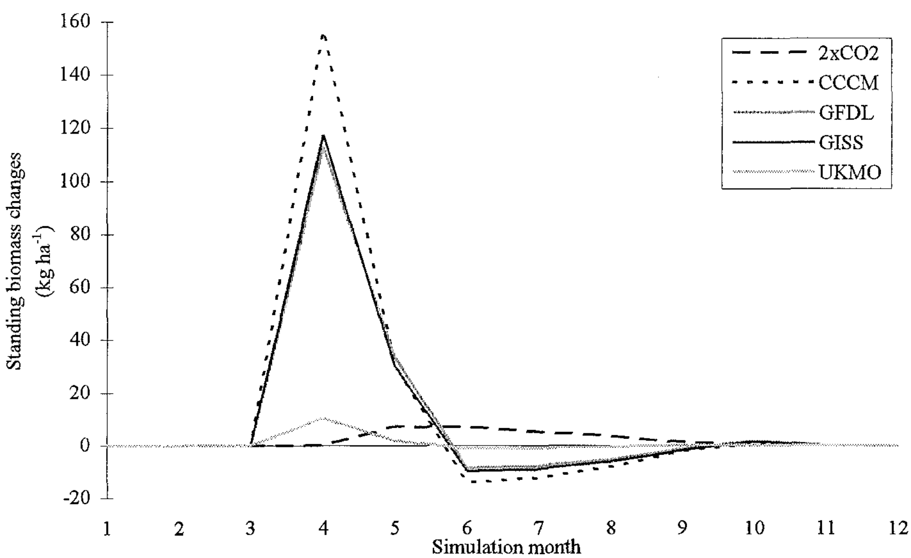


Fig. 2. Change from baseline of standing biomass (kg ha^{-1}) under different scenarios for (a) Hutag and (b) Dalanzadgad.

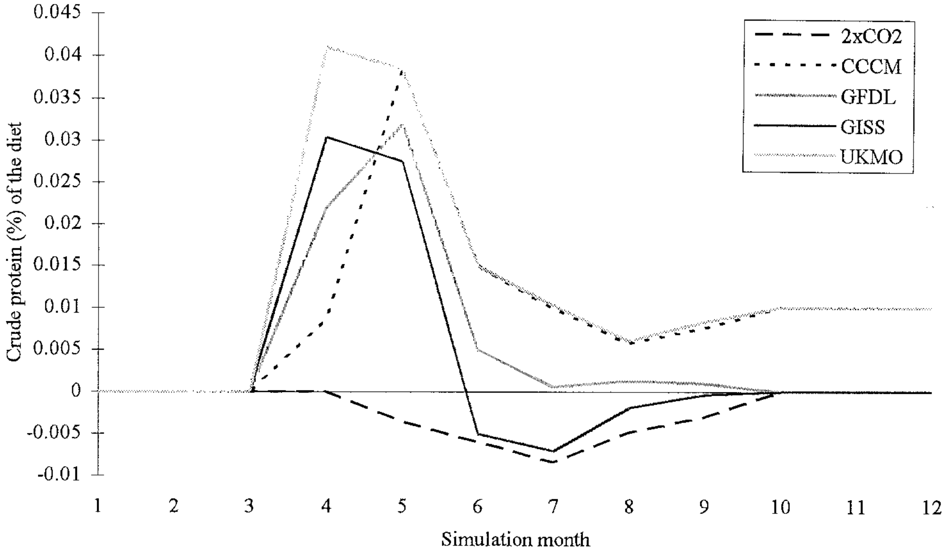


Fig. 3. Change from baseline of crude protein (%) of the diet selected for different scenarios for Hutag.

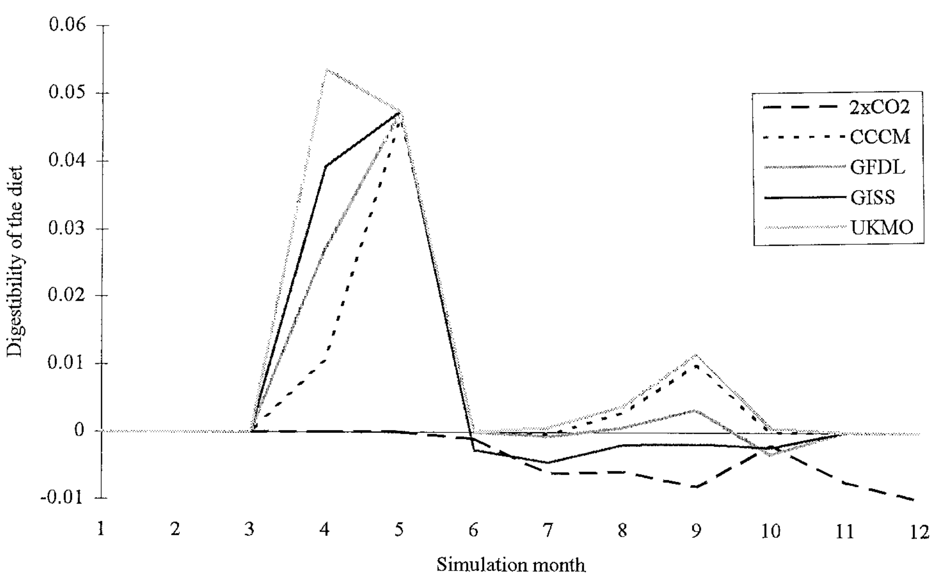


Fig. 4. Change from baseline of digestibility (%) of the diet selected for different scenarios for Hutag.

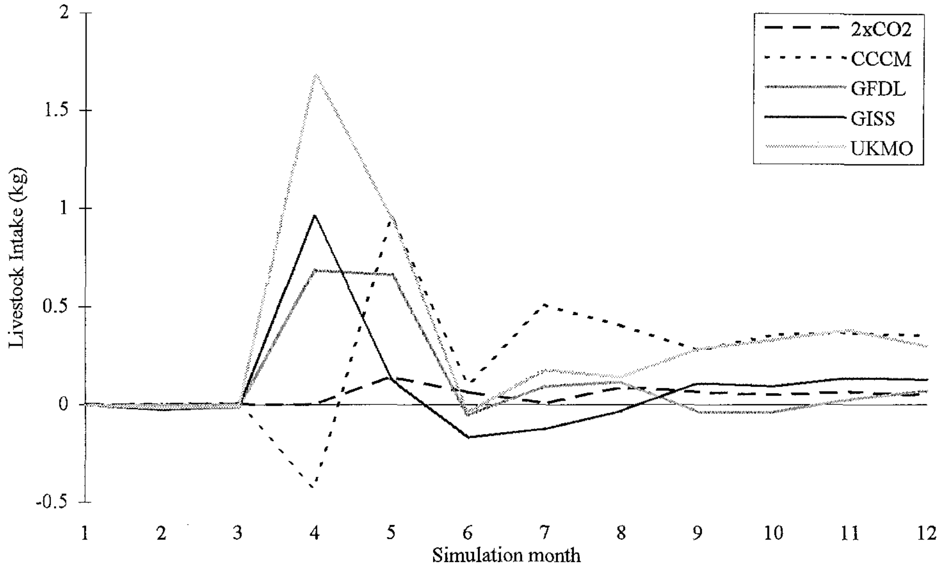


Fig. 5. Change from baseline of Mongolian steer intake (kg) for difference scenarios for Hutag.

In summer and autumn, the daily weight gain of the Selenge and Halhgol genotypes of steer, which receive supplemental feed in winter and spring, increased under the climate change scenarios (Figure 7).

4. Conclusions

Results from this study demonstrate that changes in global climate could affect pasture and livestock production in Mongolia. The impact of climate change on pasture production in the Gobi desert areas may be negative. In colder regions, climate change could have favorable effects on plant production. Because precipitation would increase in spring (March to May) under global warming, plant biomass accumulation could start early, the length of growth stages would be changed, the time of peak standing crop would occur earlier, and the growing season would be longer. Consequently, pasture plant biomass and its tissue quality are estimated to be higher in the first period of the growing season and lower in the second period. With global warming, potential evapotranspiration would rise, and the amount of water available to plants would decrease. The soil organic carbon pool is estimated to increase in the north and decrease in the south under the GCM scenarios. After flowering, with decreased above-ground standing biomass, plant nitrogen content, C:N ratio, and crude protein would be potentially decreased. With increased temperatures and lower plant quality, livestock intake and livestock weight could decline in late summer when digestibility is lower. Average daily weight gain of Mongolian steers that have only pasture forage, is estimated to be lower by 0.2 kg in the second part of the summer. All of these effects would mean a decrease in meat production of Mongolian steer. Steer weight could be lower by approximately 15-30 kg at the end of the autumn. However, the simulation indicated that there would be no negative effects on the weight gain of steer that are provided supplemental feed.

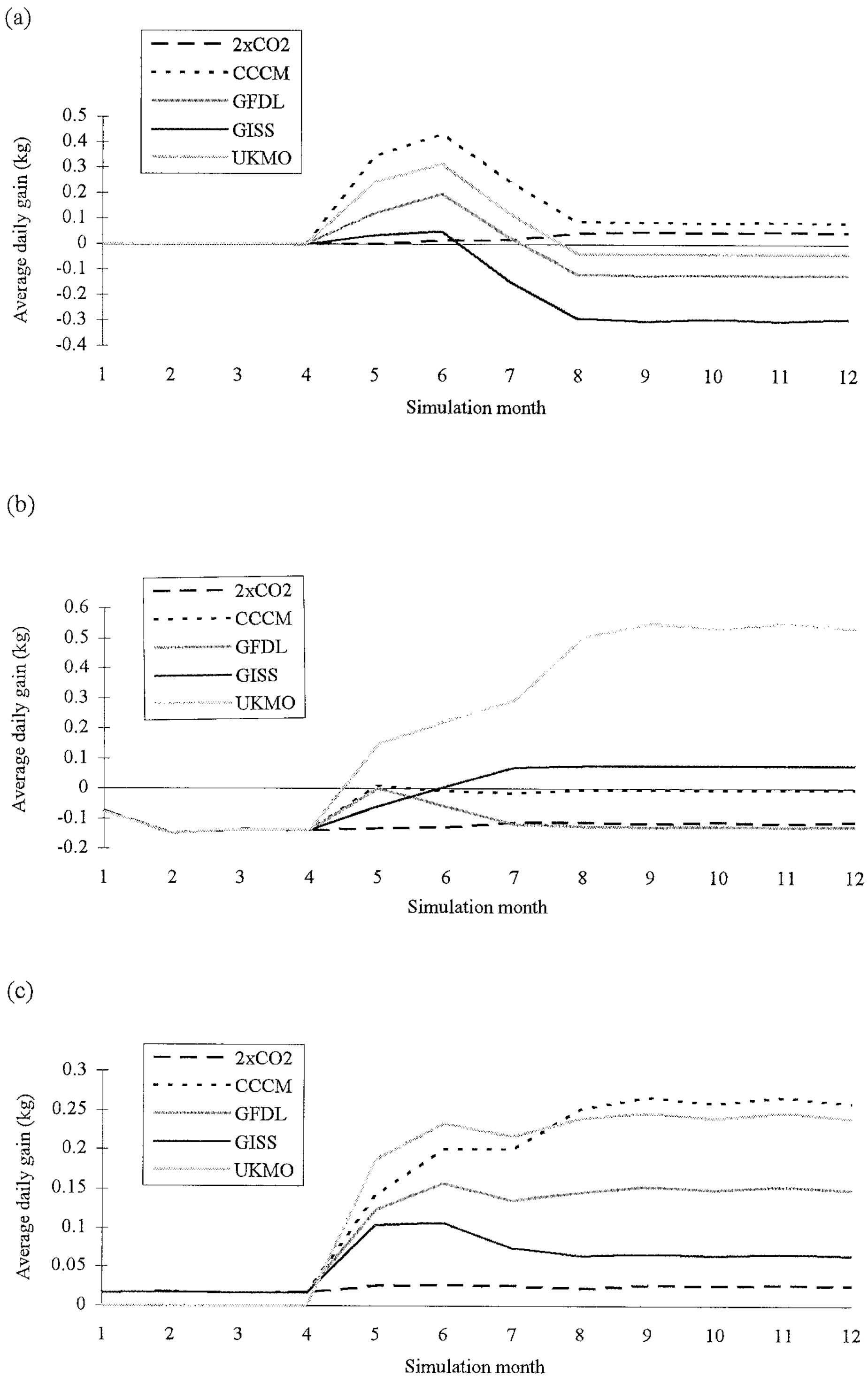


Fig. 6. Change from baseline of average daily gain of Mongolian genotype steers under different scenarios for (a) Tsetserleg, (b) Hutag, and (c) Halhgol.

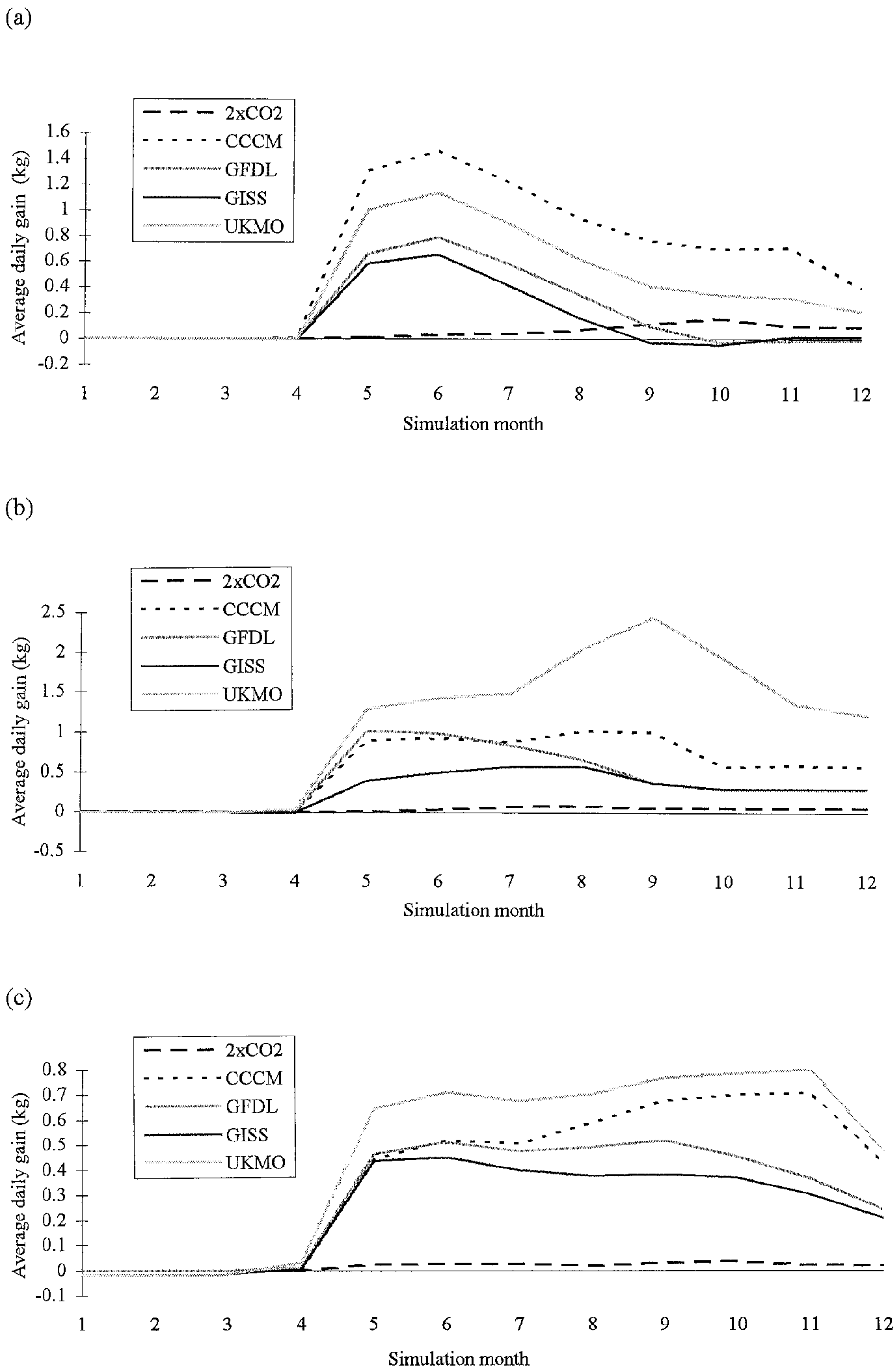


Fig. 7. Change from baseline of average daily gain of Selenge genotypes for (a) Tsetserleg and (b) Hutag, and Halhgol genotypes for (c) Halhgol.

To keep livestock production at its present level, adaptation options must be considered, such as strengthening of forage reserves that are set aside at the end of summer to provide a supply of fodder.

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