Report on grassland ecosystem manipulation experiments

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Content

Summary

We report information and preliminary results on grassland ecosystem manipulation experiments located inside and outside Europe. Five sites of seven have manipulated rainfall in field conditions, one site has manipulated atmospheric CO_2, and one site has manipulated atmospheric CO_2 in combination with temperature and rainfall. The three sites located outside of Europe (Brazil, Senegal, South Africa) had set up new field experiments during the course of Animal Change project with a new design of shelters allowing partial interception of rainfall. This report synthetises information given by each principal investigator during a workshop organised before the 3rd annual meeting of Animal Change in Madrid. In Ireland and Switzerland, rainfall was totally intercepted during 10 weeks in Summer time on 15 mixtures (1, 2, 4 species) of four agriculturally relevant species. In Senegal, South Africa and Brazil, new experiments were setup with the same shelter design in order to intercept fraction of rain during the growing season. For these three sites, arid, semi-arid and tropical grasslands were studied, respectively. In Hungary and France, other climate change drivers, atmospheric CO_2, air temperature and rainfall were also manipulated in more controlled conditions on perennial grassland vegetation. Preliminary results showed that in moderate drought conditions occurring in Switzerland, legumes and deep rooted species performed better than grasses and shallow rooted ones. Whereas in Ireland as more severe drought conditions occurred this pattern was not observed. For the three experiments located outside Europe, % of precipitations interception ranged between 15 to 75%. In semi-arid climatic conditions, interception of up to 50% of precipitations during 5 months had no effect on production. But when vegetation received only 25% of the rainfall, a decline of production was observed. In this ecosystem, changes of phytomass were explained by climatic stress index like precipitations – potential evapotranspiration (P – PET). In subtropical climatic conditions encountered in South Africa, reduction of precipitation had a strong negative (-49%) effect on herbage yield in January and February, however in November, only about 19% of rainfall intercepted induced the same effect. These results stressed vulnerability of the semi-arid grassland that has been detected from about 19% of rainfall interception in November. In Brazil, the experiment has been setup and the shelters tested in 2014. Rainfall are intercepted and added in order to simulate climate scenario for the southern Brazilian region, with some regional models predicting increase, others decrease in precipitation. Overall, preliminary results observed for the different sites emphasised potential changes of grassland production and forage quality induced by changes in precipitation for different climatic zone areas. However, sites comparison will be possible when climatic and grassland production data will be available for all sites.

1 Preamble

Rainfall manipulation experiments outside Europe (except Senegal) started with an important delay due to administrative reasons, which explains the deliverable delay.

We remind here that the two European sites (Ireland, Switzerland), involved in WP7 (Task 7.2), were also included in this report, as they manipulate rainfall on some grassland species.

2 Introduction

The reports of IPCC (2007, Seneviratne *et al.* 2012) clearly indicated a global air warming since 1990's while atmospheric CO_2 concentration has increased by +120 ppm since the end of XIXth century. There are increasing evidences that change of rainfall variability due to climate change induced more extreme climatic events such as heat weave. However there are large uncertainties on their occurrence due to difficulties to simulate local events. And it is now expected that severe droughts have important effects on terrestrial ecosystems (Bahn *et al.* 2014).

Grassland is a widespread ecosystem that offers many ecological and agronomical services (forage production, biodiversity, soil carbon sequestration) that tie in to human activities. The sustainability of these agro-ecosystem services thus depends on the combined effects of both climate and management-driven disturbances (Soussana & Duru, 2007; Tubiello *et al.*, 2007). Climate change is expected to have contrasting effects on grasslands services: (1) positive effects of elevated atmospheric CO_2 (Campbell *et al.*, 1990; Teyssonneyre *et al.* 2002) and temperature on above-ground production but with an average air warming of 3.5°C the positive effect was cancelled after 2 years (Cantarel *et al.* 2013); (2) negative effect of drought (Knapp et Smith 2001; Gilgen & Buchmann, 2009; Zwicke *et al.* 2013); (3) null effect of drought (Kreyling *et al.*, 2008; Jentsch *et al.*, 2011), which has been ascribed to a buffering effect induced by the presence of different functional types ('insurance hypothesis' according to Yachi & Loreau, 1999), or to the size of rain event (Swemmer *et al.*, 2007; Cherwin & Knapp, 2012). Furthermore, these simple effects may be counteracted by effect of combination of climate variables, thus making difficult to predict ecosystem response to full combination of climatic variables in field conditions (Dieleman *et al.*, 2012). It is also emphasised that these responses mainly depend on duration, intensity and threshold of climatic variables.

We aim comparing grasslands responses to manipulation of rainfall, atmospheric CO_2 and air temperature, in different climates inside and outside Europe (Table 1).

Table 1: List of sites involved in grassland manipulation experiments

Country	Site name	Climate	Vegetation type	Management	Manipulation
Ireland	Wexford	Sub-humid	Sown grassland species	Mowing, fertilisation	rainfall interception for 10 weeks
Switzerland	Reckenholz	Sub-humid	Sown grassland species	Mowing, fertilisation	rainfall interception for 10 weeks
	Tänikon	Sub-humid	Sown grassland species	Mowing, fertilisation	rainfall interception for 10 weeks
Brazil	Porto Alegre	Sub-tropical	Pampa & Mata Atlantica	Grazing simulation	rainfall interception and addition
South Africa	Pretoria University	Sub-tropical	Semi-arid grassland	Mowing	Rainfall interception
Hungary	Gödöllő University	Continental	Perennial grassland	Mowing	CO_2
France	Ecotron Montpellier	Sub-humid	Perennial grassland	Mowing	CO_2, temperature, rainfall

During the workshop organised before the 3rd annual meeting in Madrid (21st May), it has been emphasised that sites comparison will depend on defining stress indicators as proposed by Vicca *et al.* (2012).

What are the useful metrics to assess drought stress on grassland and to compare sites?

- Amount of available water for plants (soil water content, soil texture, root and soil depths, SWC at field capacity and wilting point: soil water holding capacity)

- Leaf water potential, leaf relative water content

- Climatic water balance: Precipitation – Potential evapotranspiration (Vicente-Serrano et al 2010)
  - ✓ PET integrates effect of T, radiation, wind speed during stress

It was asked to each site PI to supply climatic data in order to calculate these indicators. The list is written below.

Data needed for between sites comparison of above-ground production

- Long-term climate of the site
  - ✓ Annual and growing seasons precipitations and potential evapotranspiration (PET, mm). For PET: cumulation by growing season, year. T, P
- Vegetation, soil and management data
- During the rainfall manipulation (if available)
  - ✓ Soil and root depth
  - ✓ Duration and intensity of stress
  - ✓ Soil water content (root zone profile)
    - ✓ At field capacity and wilting point to calculate relative available water (texture of soil may be used to calculate these thresholds)
  - ✓ Leaf water potential or leaf relative water content

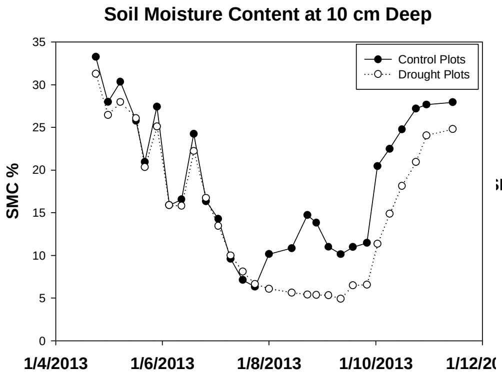
During the workshop, each PI showed main progress and preliminary results.

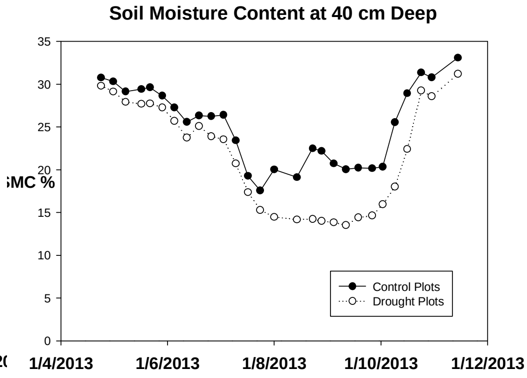
Program of the workshop held in Miguel Angel Hotel, 21st May 2014
14:00-14:05 Introduction
14:05-14:20 Ireland site
14:20-14:35 Swiss site
14:35-14:50 Hungary site
14:50-15:05 France site
15:05-15:20 Senegal site
15:20-15:35 South Africa site
15:35-15:50 Brazil site
15:50-16:15 Conclusions

3 Rainfall manipulation experiments

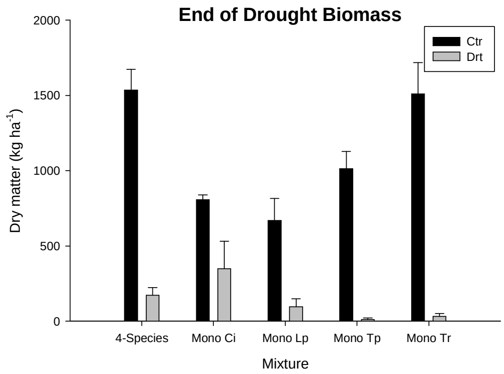
3.1 Site from Ireland

The experiment was setup at Wexford (Teagasc Environment Research Centre, Johnstown Castle) in 2012 and rainfall manipulation started in July 2013 (100% of rainfall exclusion for 10 weeks).
15 mixtures (1, 2, 4 species) of 4 agriculturally relevant species: *Lolium perenne* (ryegrass), *Cichorium intybus* (chicory), *Trifolium repens* (white clover), *Trifolium pratense* (red clover) were sown in March 2012. Effects on aboveground productivity, species composition and chemical composition were measured. Soil cores were extracted in early November to determine root biomass and root length by class diameter.
Rain-out shelters were designed to allow maximal air-flow to minimise temperature and humidity changes under the shelters with open ended and top roof vent. Air temperature and humidity inside and outside the shelters was monitored using data-loggers housed in mini-Stephenson screens.
Rainfall interception was applied in July.
Soil moisture content was measured using a Delta-T Profile Probe, weekly in nine pairs of plots at: 10, 20, 30 and 40 cm deep. Large differences between soil moisture at 10 and 40 cm deep were observed. The control treatment dropped below 10% at 10 cm depth, this was due to a summer heat wave.

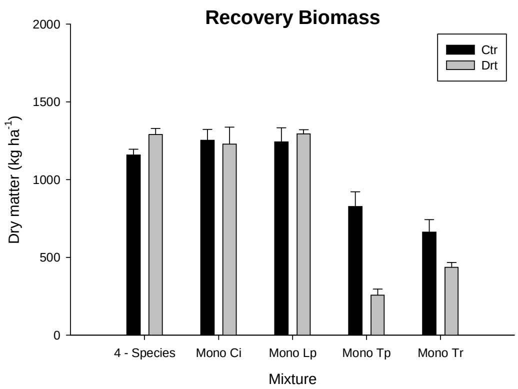




The severe drought conditions had a large impact on all mixtures.



The recovery was best for the 4-species mixture, Chicory and *Lolium* monocultures (which also made up the main proportion of the 4-sp mixture).

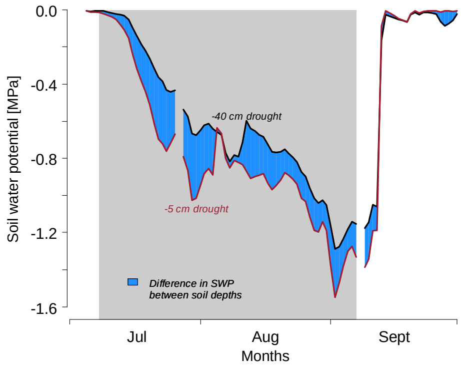


3.2 Sites from Switzerland

The experiments were setup at two sites, Reckenholz and Tänikon. The species used and mixtures were the same as the ones used in Ireland.

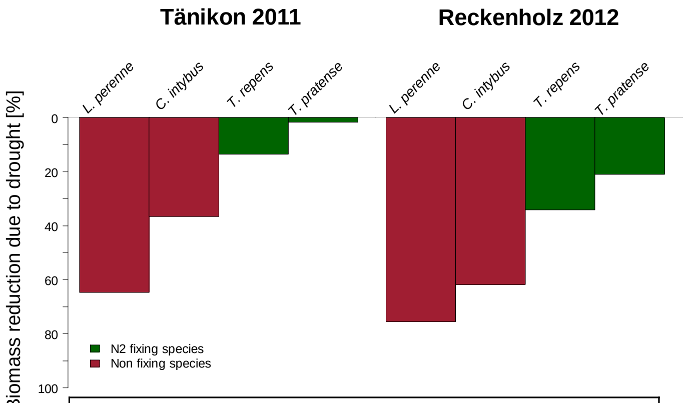
Soil water potential declined progressively to -1.6 MPa at the end of rainfall interception at 5cm depth whereas at 40cm depth, it declined to about -1.4 MPa. Deep rooted species have access to water below 40cm and are less limited compared to shallow rooted species.

Soil water potential measured at Reckenholz site during the period of rainfall interception



Whatever the site and the year Lolium and Chicory had lower biomass in response to rainfall interception than the two clover species.

Percent reduction in biomass at end of drought



P = 0.005	N_2 fixing *vs.* non-fixing	P = 0.001
P = 0.061	Deep *vs.* shallow rooted	P = 0.104

Effect on herbage yield:

Tänikon:
Lp: –65%
Ci: –37%
Tr: –14%
Tp: – 2%

Reckenholz:
Lp: –75%
Ci: –61%
Tr: –34%
Tp: –21%

Conclusions

1) Functional types of species that are able to resist drought?

- Deep rooted species perform better than shallow rooted
- N_2 fixing species perform better than non-fixing

2) How can the varying drought resistance be explained?

a) Deep rooted species have access to water from deeper levels

a) N_2 fixing species suffer less from restricted soil N availability

3.3 Site from Senegal

The experiment was setup on a rangeland located in northern Senegal from 2011 to 2013.

The first year 2011, the aim was to setup and test the rainout shelters. The rainy season occurred from June to October, mean air temperature was 25.1°C in January and 32.7°C in June; annual rainfall was 345.2 mm. The soil is a sandy clay type.

Rainout shelters were built according to the design of Yahdjian and Sala (2002). It consisted in a metal frame (2 x 2 m, 0.75-1.15 m height) with a pitched roof formed of translucent strips (17 cm wide); their number depends on volume of water intercepted.

A randomized complete blocks design was applied with four treatments of rainfall interception: 0%, 25%, 50% and 75%, and 5 replicates each. Volume of water intercepted, soil water content (horizons 0-15 cm and 0-30 cm); photosynthetic radiation (under cover and ambient); air temperature were measured.

The shelters were left in the field for 4-5 months from June to October.

The percentage of water intercepted is slightly higher than the expected value (Tab. 2), in contrast to those obtained by Yahdjian and Sala (2002) which were slightly lower. This yielded no change of soil water content either at 0-15 or 0-30cm. For the treatment 75% of rainfall interception, 20% of light was intercepted by the roof and air temperature increased by about 0.5°C, whereas these effects were not detected for the other treatments.

Table 2: Annual values of rainfall and percentage of rainfall intercepted for the 3 years experiments.

Year	2011	2012	2013
Annual rainfall (mm)	345	377	303
Rainfall intercepted ± SD (%)			
25%	28.06 ± 2.86	30.53 ± 8.26	28.72 ± 15.77
50%	54.40 ± 5.72	58.02 ± 12.44	48.40 ± 17.72
75%	81.46 ± 10.84	88.75 ± 16.36	64.78 ± 20.34

In 2012 and 2013, a similar experimental design was setup, but with 10 replicates and larger shelters (4 x 2 m, 0.75-1.15 m height) in each treatment. The number of stripes depends on the volume of water intercepted: 6 for the treatment 25 %, 12 for 50 % and 18 for 75 %. Lower rainfall was intercepted in 2013 in comparison with 2012 in the 50 and 75% treatments. This may be explained by the rain event size, i.e. a low size event yielded higher rainfall interception than during a high rainfall event.

Table 3: Annual P-PET values measured during the three years experiment for the four treatments.

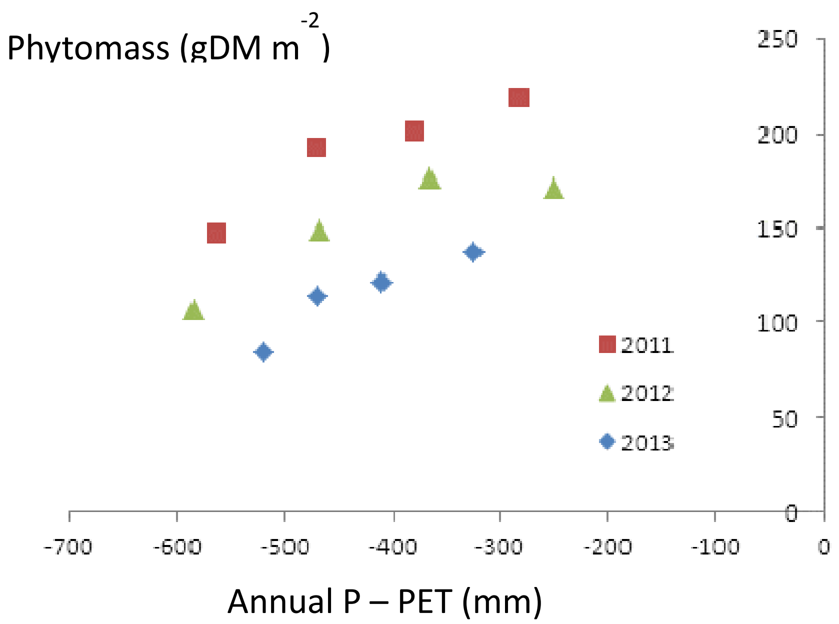
Treatments	P - PET 2011	P - PET 2012	P - PET 2013
Control	-282	-250	-324
25%	-379	-365	-411
50%	-470	-469	-471
75%	-563	-585	-521

Herbaceous phytomass was lower in 2012 than in 2013: 107-176 g DM m^{-2} and 84.6-137 g DM m^{-2}, respectively. In 2012, phytomass was only reduced under the 75% treatment, whereas in 2013 no treatment effect was observed (Table 4). For both years, proportion of grasses increased by about 14% in the 25% treatment at the expense of legumes. This effect was more pronounced for the 50% treatment and in 2013 (+24%). In the 75% treatment, legumes declined by 24 and 30% the first and the second year, respectively. Forbs and grasses also increased in this treatment. Overall legumes are promoted by favorable water conditions because the rainfall was higher in 2012 than in 2013 while grasses are better adapted to water deficit.

Table 4: Herbaceous phytomass (g DM m^{-2})

Year	2011	2012	2013
Control	219 a	171 a	137 ab
25%	201 a	176 a	121 b
50%	192 a	149 ab	114 b
75%	147 a	107 b	84.6 b

Within a year, different letters correspond to significant differences ($P < 0.05$).



Relationship between phytomass and annual P – PET for the four treatments measured each experimental year.

<u>Conclusions</u>

In this arid ecosystem, reduction of rainfall by 75% showed a trend to reduce phytomass by 36% although this effect was not significant. Changes of annual P – PET explained most of the decline of phytomass. Furthermore, changes of forage quality are expected in these more arid conditions as legumes were the most vulnerable functional group.

3.4 Site from South Africa

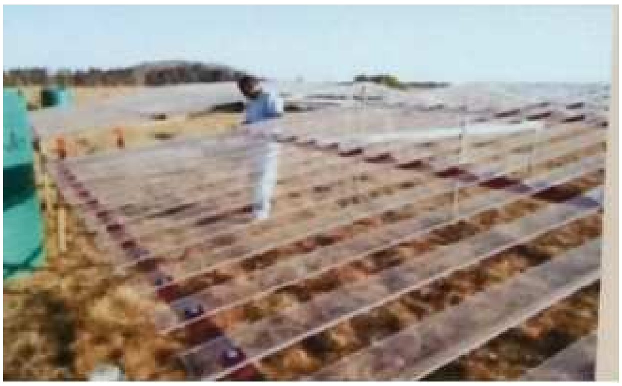
In September 2013, the experiment was setup at Hatfield experimental farm, University of Pretoria (UP), on a semi-arid grassland ecosystem: 1370m a.s.l., 18.3°C air temperature: 23.5-13.2°C: max-min range; 672 mm annual rainfall and 664mm during the growing season; sandy loam soil. The vegetation is a mixed veld, dominated by *Heteropogon hirta*, *Eragrostis lehmannania*, *Ipomoa craccipes*, and a lot of forb species.

The aim was to setup, test the rainout shelters and obtain first results of harvest yield after rainfall manipulation. Rain interception treatments included five replicates of four levels of (0, 15, 30 and 60% reduction of each rainfall event). Each rain-out shelter was built in an area of 7m x 7m plot size fitted with acrylic bands. Each acrylic bands or panel are 7 m long, 0.13 m wide and 2.5 mm thick. The roofs have an inverted V-shape design with 10° inclination in order to minimize the effect of rainfall coming at angle from the longer section of a slope. The incoming rain has been diverted to 'JoJo' tanks of 1.42 m in diameter and 1.6 m height with a volume of 1500 (5 plots) and 2200 litres (10 plots).

Data were collected on initial soil sample, pre-rain and early rain plant species composition (forbs, herbs and grasses), soil moisture using neutron probe (NP), photosynthetic active radiation (PAR), and biomass yield from first and second harvests.

The preliminary results indicated that the shelters are capable of diverting the hypothesized amount (volume) of water (9.1-30%, 23-47% and 53-73.1% for 15%, 30% and 60% plots, respectively). Data collection under the structure will continue including other parameters till the end of 2015.

View of the shelters during the setup



In the 15%, 30% and 60% rainfall interception treatments 18.7, 32.2 and 59% of the rainfall were excluded from the plots, respectively (Table 5). Rainfall manipulation occurred from October 2013 to April 2014.

After one month (November, first harvest) of rainfall interception, all plots were uniformly harvested and then every month (for moderate grazing intensity) and every 1.5 months (for low grazing intensity) plots.

Table 5: Percentage of rainfall intercepted for each treatment.

Year	2013
Temperature (°C)	18.3°C; 23.5-13.2°C: max-min range
Annual rainfall (mm)	672
Rainfall intercepted (%)	
15%	18.7
30%	32.2
60%	59

The control, 15 and 30% treatments were dominated by major grasses, *Digitaria eriantha* and *Setaria sphacelata* var *Torta*, and *Ipomoa crassipes* (forb) and *Elephantorrhiza elephantine* (dwarf shrub). In contrast, *Eragrostis lehmanniana* was a dominant grass in the 60% treatment.

The herbage yield of the first harvest (November) of the control was about twice higher than the three treatments (15, 30, 60%) (Table 6). This trend was maintained between the control and the 60% treatment for the second (January) and the third (February) harvests, but lower differences between the control and the 15 and 30% treatments were observed.

Table 6: Herbage yield (mean ± se, g m^{-2}) as affected by simulated drought.

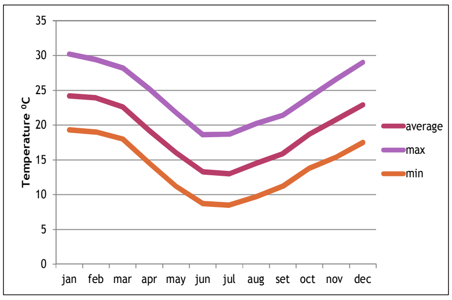
RFI	First harvest	Second harvest	Third harvest
0	20.62 ± 1.75^{a}	56.5 ± 5.64^{a}	70.25 ± 6.06^{a}
15%	10.13 ± 1.69^{b}	47.21 ± 4.33^{a}	56.18 ± 5.49^{ab}
30%	10.81 ± 1.50^{b}	50.2 ± 4.93^{a}	56.18 ± 4.00^{bc}
60%	8.55 ± 1.47^{b}	28.71 ± 2.29^{b}	36.23 ± 3.78^{c}

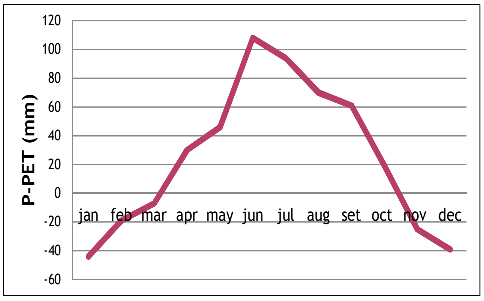
Treatment means (a,b) with different letters are statistically different at $p < 0.05$

<u>Conclusions</u>
Interception of about 59% of rainfall had a strong negative (-49%) effect on herbage yield in January and February, however in November, only about 19% of rainfall intercepted induced the same effect. These results stressed vulnerability of the semi-arid grassland that has been detected from about 19% of rainfall interception in November. This may be due to the moisture stress associated to less amount of rain at early growing period (before the pasture has been well established) and higher evapotranspiration due to higher temperature.

3.5 Site from Brazil

The experiment was setup in 2014 at the Faculty of Agronomy, Eldorado do Sul-Southern Brazil, close to Porto Alegre (30º05'27"S, 51º40'18"W, 46 m a.s.l.) on a Pampa biome. The climate is subtropical, higher (~25°C) and lower temperatures (~ 13°C) are observed in January and June-July, respectively (Fig left). Climatic index (P – PET, mm), Precipitation (P) – potential evapotranspiration (PET) fluctuates from -40 (January) to +110 mm (June-July) (Fig right).



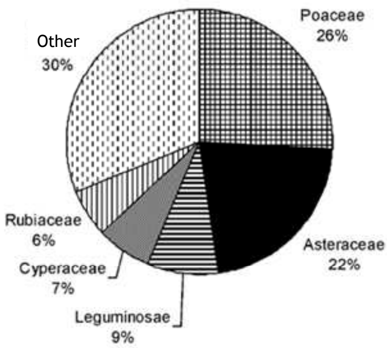


The soil at the experimental site is classified as an Acrisol (FAO classification), which is a deep soil, with a clay-enriched subsoil, low-activity clay, and low-base status. The A horizon, with a pH of 4.5, contains about 26% of clay, 2 ppm of P, 80 ppm of K, 3% of organic matter, and presents a Cation Exchange Capacity of 4.9 mEq/dl, with 1.5 mEq/dl of Al, 1.3 mEq of Ca and 0.9 mEq/dl of Mg.

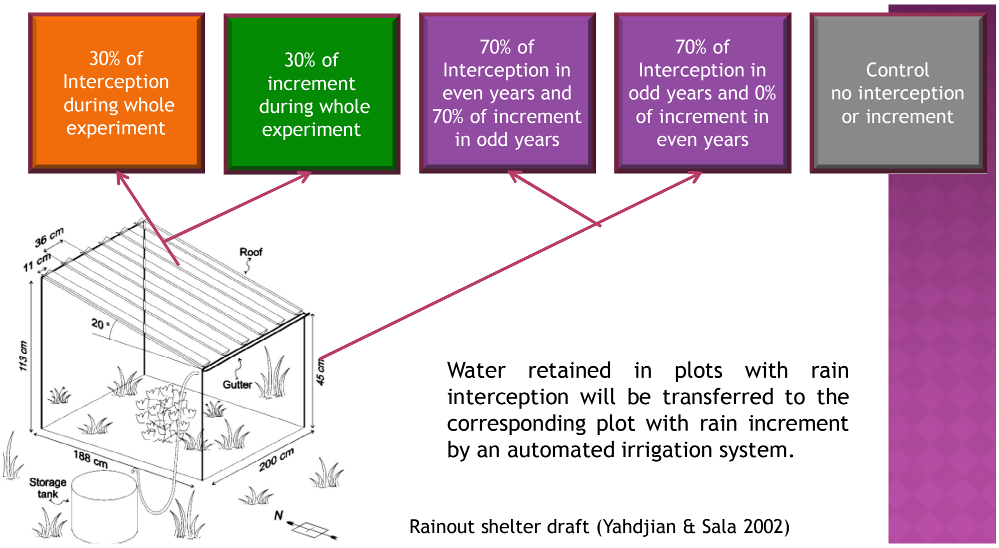
<u>Vegetation and previous management</u>

The vegetation in the area is native grassland (*Campos*) with no record of other disturbances other than grazing by livestock, mainly cattle, and sporadic mowing to control shrubs. The plant community is dominated by stoloniferous (e.g., *Axonopus affinis*) or rhizomatous (e.g., *Paspalum notatum*) prostrated plants, with scattered shrubs (*Baccharis* spp., *Vernonia nudiflora*), and tussocks grasses (e.g., *Andropogon lateralis*).

- Several grass, forbs and shrubs species.
- Composition and functional traits highly depend on disturbances as grazing.
- Specific leaf area increases with grazing intensity,
- while LDMC, presence of caespitose, hemicryptophytes and C4 species decreases.
- Under low grazing intensity, development of tussock grasses
- which leads to a double strata vegetation structure. Tussock caespitose grasses in a matrix of stoloniferous and prostate species.



The experiment consists in 25 main plots (1.1 x 1.1 m), 5 replicates (blocks) and 5 treatments of rainfall manipulation. Rainfall are intercepted and added in order to simulate climate scenario for the southern Brazilian region, with some regional models predicting increase, others decrease in precipitation.

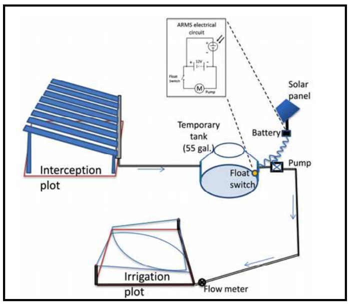


Water retained in plots with rain interception will be transferred to the corresponding plot with rain increment by an automated irrigation system.

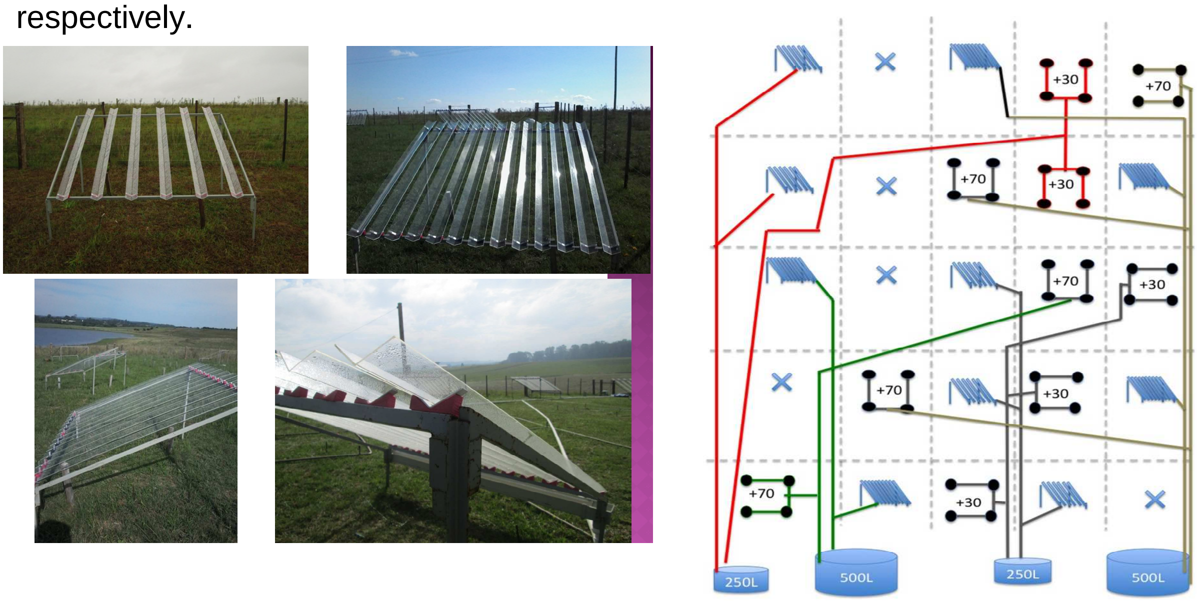
Rainout shelter draft (Yahdjian & Sala 2002)

The rainfall increment treatment, rainfall intercepted by the shelters is diverted to a temporary tank and then pumped to the irrigated plots.

The Automated Rainfall Manipulation System (ARMS) (Gherardi & Sala, 2012, Ecosphere)



View of the shelters (left) and of the different treatments (right). The rain intercepted in the 30% and 70% treatments is used to irrigate the +30% and +70% treatments, respectively.

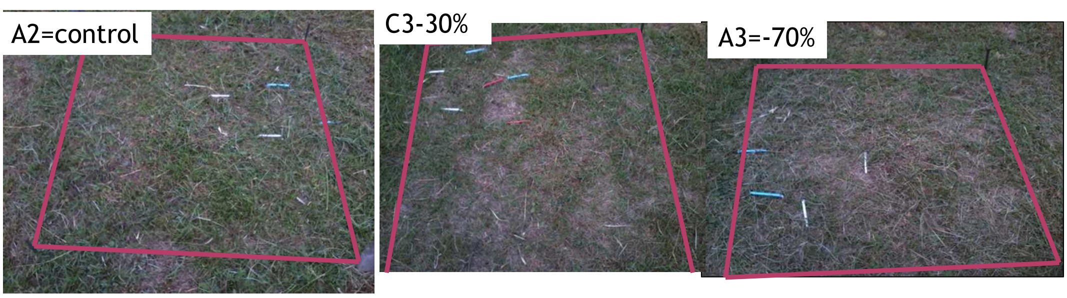


According to Yahdjian & Sala (2002), the 30% interception treatment was effective in intercepting the expected amount of water, with no significant differences between the observed and the expected water interception for those treatments. In contrast, water interception in the 80% shelters was significantly lower than the expected value ($P<0.05$) and accounted for 71% of incoming rainfall. We expect the 70% interception treatment to be effective for at least 60% of interception. Field measurements of rain interception and soil moisture were not performed yet. Soil moisture sensors and data loggers will be installed in September 2014.

The 30% interception started in January, the 70% interception started in February and the rain addition (both treatments) started in May.

Vegetation response to rainfall interception

≅3 months after installation



In addition, the effect of grazing intensity, assessed by treatments of cutting frequency, will be assessed within all rainfall treatments.

Preliminary observations

The average biomass collected at the beginning of the experiment (January), on 50 x 50 cm plot was 2.95g on 300^o day. After 5 months of rain interception treatment, the average was 1.71, 2.31 and 1.77g, but no statistical difference was verified. Also, when comparing the proportion of changes in productivity (May/January productivity) by plot, there was no clear tendency of response.

Conclusions

These preliminary results are only based on the first months of the experiment, where it is affected by the first phase of treatment adjustment.

4 Atmospheric CO_2 manipulation experiment

Site from Hungary

The experiment was setup at the Botanical Garden of the Szent István University, Gödöllő, Hungary) with transplanted loess grassland monoliths (Salvio nemorosae – Festucetum rupicolae) dominated by perennial C_3 species.

The response of grassland to elevated CO_2 was studied with open top chamber (OTC) system that was set up and restarted in 2011 with new control hardware. In the open top chamber experiment (diameter: 1.28 m, height: 1 m), three types of treatments are applied: 1) chambers with elevated CO_2 (650 ppm), 2) control chambers (380 ppm), and 3) field control plot (3 replicates at each treatment).

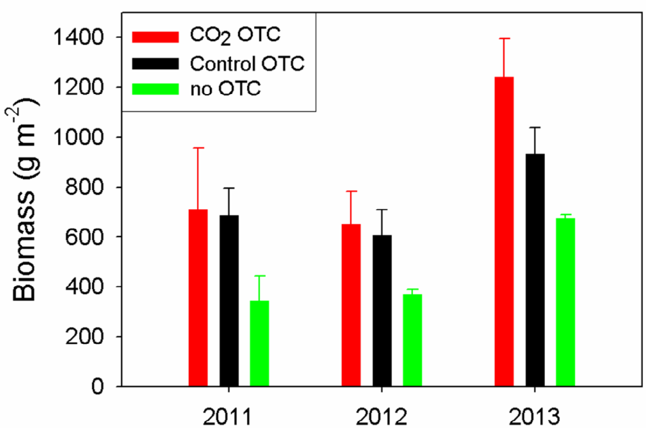
Table 7: Annual values of potential evapotranspiration (PET), rainfall and climatic index (P – PET) for the three years experiment.

year	PET (mm)	rainfall (mm)	P-PET (mm)
2011	914	381	-533
2012	941	466	-476
2013	908	575	-333

Annual P – PET ranged between -333 mm in 2013 to -533 mm in 2011, indicating higher climatic stress full conditions in the first year than in the third one, whereas 2012 was intermediate (-476mm) (Table 7).

Because of the chamber-effect, soil water content (SWC) in the upper 30 cm of the soil was lower in the chambers by 3% (v/v) on average than in the field plots, and soil temperature in the chambers at 3 cm depth was 1.5°C lower than in the free air parcels probably due to the shading effect of the larger biomass in the chambers.

Elevated CO_2 increased by 25% the biomass only the third year in comparison with the control OTC. In the free air parcels biomass values were significantly lower by 43% than in the two OTC treatments.



Biomass production measured inside (red and black bars) and outside (green) the open top chamber (OTC). Mean + SD.

Conclusions

Elevated CO_2 had a positive effect on biomass production when climatic conditions were less stressful, like in 2013, than in drier years (2011 and 2012).

5 Multiple climatic manipulation experiment

Site from France

The experiment was setup in the Ecotron facility of CNRS Montpellier (south of France), to study the effects of elevated CO_2 combined with warming and reduction of precipitation on the resistance and recovery of grassland monoliths to a summer extreme event (heat weave combined with drought stress).

Perennial grassland monoliths were extracted from an upland area (850m a.s.l.) where the climate is semi-continental with oceanic influences. Average annual air temperature is 8.0°C, with an annual cumulated rainfall of 806 mm (1969-1999 long-term average). Soil is a sandy loam granitic brown soil (50 % sand, 24 % silt, 25 % clay) with 39 % organic matter, C:N = 9.6 and pH_{water} = 5.9. Soil water content (SWC, weight based), measured at field capacity and at wilting point was 25.0 % and 13.4 %, respectively.

Table 8: Long-term climatic data, soil characteristics and vegetation of the field site.

Long-term Climate	P (mm)	T (°C)	P – PET (mm)	Soil water holding capacity	Soil type, depth	Vegetation
annual	806	8.6 ± 0.5	108 ± 202	14 mm	Clay: 21% Silt: 19% Sand: 59% 0.6 m	➢ 75% grasses ➢ 15% legumes ➢ 10% non N-fixing dicots
Growing season	650	10.7 ± 4.7	28			

At the end of Summer 2009, the monoliths were extracted from a semi-natural upland grassland and then transferred to Montpellier. The first year of the experiment (2010), all monoliths were acclimated to a future climate, i.e. warmer (+4°C) and drier (-56 mm precipitations). The second year (2011), half of the monoliths was subjected to elevated CO_2 concentration and a summer extreme event was applied to half of the monoliths in each CO_2 concentration. Four treatments were considered: ambient CO_2 with and without extreme: 380C and 380E, respectively, elevated CO_2 with and without extreme: 520C and 520E, respectively.

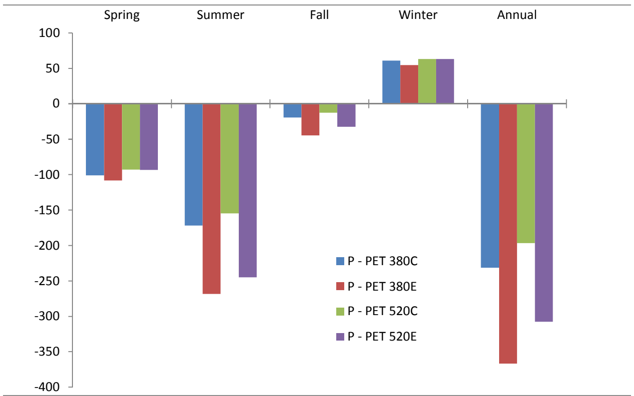
Monoliths extraction in the field site

View of the Ecotron facility in Montpellier

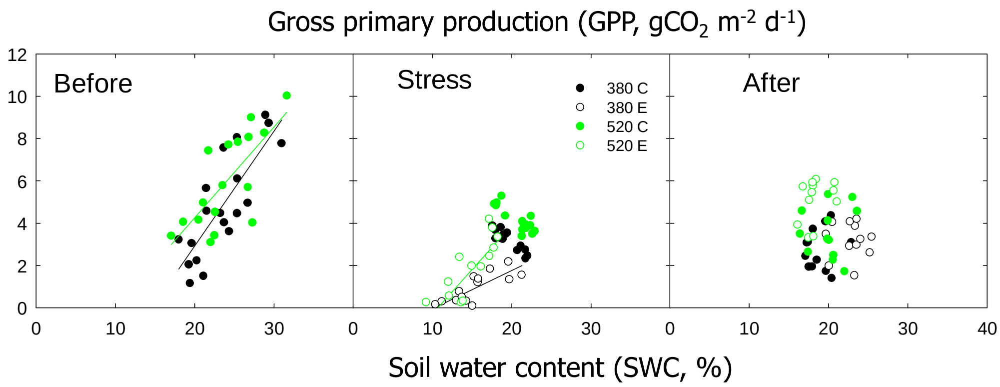
View from inside of one macrocosm

The climatic stress indicator (P-PET) reached -100mm in Spring and declined to less than -150mm for the control treatments in ambient (380C) and elevated CO_2 (520C). In both extreme treatments (380E, 520E), P-PET decreased to less than -250mm. This yielded very 'dry' conditions in comparison with long-term average climatic data.

Stress indicators: P – PET (mm)

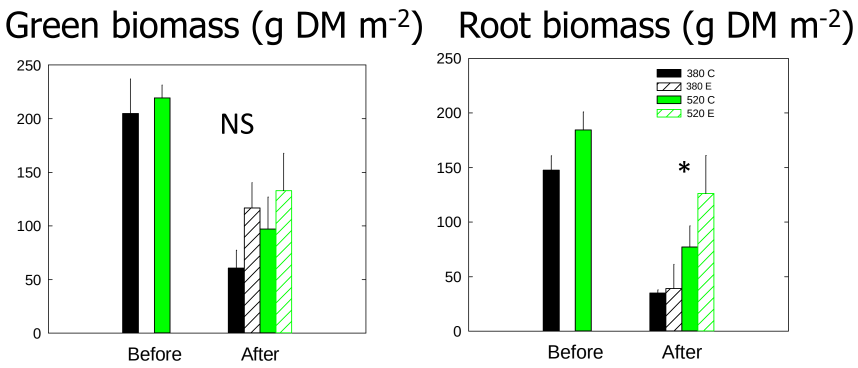


We show that under elevated CO_2 concentration, monoliths had higher canopy photosynthesis and lower evapotranspiration, whatever the considered period, increasing water-use efficiency (WUE).



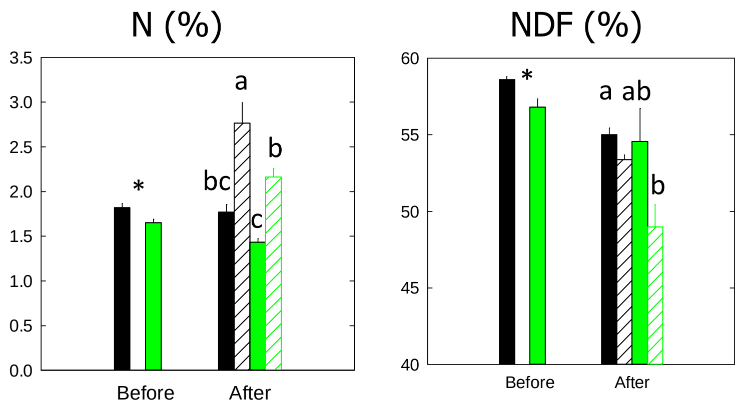
Relationship between GPP and soil water content measured before the stress in Spring, during the stress in Summer and after the stress during the rehydration period in Autumn.

The resistance and recovery to drought was markedly higher under elevated CO_2 (higher photosynthesis, leaf elongation of one target species, root growth, tissue greenness). Surprisingly, above-ground mass measured before and after the extreme was unaffected by the treatments.



Green above-ground biomass (left) and root biomass (right) measured before the stress in Spring, and after the stress during the rehydration period in Autumn.

In addition, induced-elevated CO_2 nitrogen decrease was compensated by induced-extreme drought nitrogen increase, whereas fibre increased, meaning that an increase of forage digestibility is expected under future climatic conditions.



Forage N content (left) and neutral detergent fibers (right) measured before the stress in Spring, and after the stress during the rehydration period in Autumn.

Conclusions

Under future climatic conditions (warmer and drier) forecasted for 2040-2060, elevated CO_2 may mitigate the negative effect of drought x heat by increasing GPP and water-use efficiency, and promote recovery of permanent grassland. These changes led to higher root biomass but with no effect on above-ground production. Whereas forage quality was affected: more digestible forage but containing less N. Overall, this study confirmed the short-term recovery capacity of permanent grassland after severe drought and heat wave.

6 Overall conclusions

In temperate climatic conditions, vulnerability of grassland to rainfall manipulation was linked to drought intensity and not drought duration (10 weeks in Ireland and Switzerland). In Ireland drought intensity was partly driven by air temperature which accentuates species response. We also showed in temperate climate that elevated atmospheric CO_2 increased drought resistance and recovery of grassland by increasing GPP and WUE in France. In Hungary, this positive effect was observed during the least stressful experimental year.

In semi-arid climatic conditions of Northern Senegal, interception of up to 50% of precipitations during 5 months had no effect on production indicating that half of the rainfall is enough to sustain production level to that of the control in such ecosystem. When vegetation received only 25% of the rainfall, a decline of production was observed.

In sub-tropical conditions encountered in South Africa, changes of precipitations had a strong effect on herbage yield and this stressed high vulnerability of the semi-arid grassland from about 19% of rainfall interception.

Legumes may be favoured by moderate drought conditions (Switzerland), whereas in more severe drought conditions, like encountered in France, Ireland and Senegal, grasses dominated the community at the expense of legumes.

These preliminary results emphasised potential changes of grassland production and forage quality induced by changes in precipitation for different climatic zone areas. However, sites comparison will be possible when climatic and grassland production data will be available for all sites. In addition, recovery of grassland production to rainfall manipulation is very important to assess to understand resilience of grassland ecosystem to chronicle droughts. Higher atmospheric CO_2 might increase recovery and resilience of grassland production in the long-term.

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