Turkish Journal of Range and Forage Science, 2021, 2(2): 44-51
doi: 10.51801/turkjrfs.982024

Research

Turkish Journal of Range and Forage Science

https://dergipark.gov.tr/tr/pub/turkjrfs

# Ontogeny and Fire Interact to Affect Competition between Grass and Shrubs

**Halil İbrahim ERKOVAN**[1*] **Peter J. Clarke**[2] **Ralph D. B. Whalley**[2]

[1] Department of Field Crops, Faculty of Agriculture, University of Eskisehir Osmangazi, Eskisehir, Turkey

[2] Botany, School of Environmental and Rural Science University of New England Armidale, NSW, 2351, Australia

ARTICLE INFO

Received *12/08/2021*
Accepted *06/09/2021*

***Keywords:***

Grass shrubs interaction
Fire
Old and young plant

ABSTRACT

We investigated the effects of fire, grass and acacia age on the relative growth rate (RGR), relative neighbour effect (RNE), height and biomass of acacia and grass in the greenhouse condition. The experiment was arranged a completely randomized design with 10 replicates. Grass and shrubs were grown 17 weeks after establishment, thereafter, fire was applied, and observations were done 16 weeks later. Old grass tussock suppressed acacia seedling and sapling, but young grass facilitated acacia seedling and sapling. Young acacia suppressed the young grass but older acacia facilitated the growth of mature grass tussocks. After remove of biomass and the application of fire there was no significant effect but the height and biomass of all acacia seedlings were negatively affected by grasses In contrast to acacia, the effects of fire on the grass tussocks were reduced the above ground biomass.

## 1. Introduction

How do woody plants and grasses interact in woodlands and shrublands? The details of these interactions are still not clear, particularly with respect to the effects of the woody plants on grass growth and species composition. Researches are often focused on the importance of resources and disturbance. Plant facilitates other plants especially N2 fixing plants directly or actively by ameliorating harsh environmental conditions, by altering soil properties or by increasing availability of resources (Kurokawa et al., 2010). The effects of *Acacia* include the richer soil, grass leaf nutrients, reduced evapotranspiration, increased soil water due to hydraulic lift, and decreased soil water due to competition and increase grass productivity (Breshears et al., 1997; Ludwig et al., 2001; Ludwig et al., 2003; Treydte et al., 2007; Ludwig et al., 2008; Riginos et al., 2009). For example, nitrogen and phosphorus fertilization increased grass production outside and under canopies (Ludwig et al., 2001). Ludwig et al. (2003) showed that *Acacia* may lift and leaching between 75 and 225 L of water each night to area more than 300 $m^2$. Relative frequency of facilitation and competition will inversely proportional gradients of ecosystem productivity (Bertness and Callaway, 1994). The effect of species characteristics may change through ontogeny as depend on their magnitude and direction.

---

*Correspondence author: erkovan@ogu.edu.tr

Tree and/or shrub studies have shown positive effects on grass nutrition and productivity, but in addition, there are often negative effects (Higgins et al., 2000; Cramer et al., 2007). Grasses and woody plants have reciprocal competition and have contrasting growth forms. Because of different root niche, trees and/or shrubs are assumed to be able to valuable water and mineral nutrition from lower soil layers than grasses (Cramer et al., 2010). Grasses may also have both positive and negative effects on woody plants. Negative effects include suppression of tree and shrub seed germination, seedling growth and survival. Tree and/or shrubs are generally accepted as ineffective competitor when established. Because same grasses have allelopathic effects and most grasses areas have no any gaps. These situations are cause to reduction tree and/or shrub seedling growth (Nano and Clarke, 2010; Clarke and Knox, 2009; Cramer et al., 2010). Also this event contributes grass competition. While trees use mostly deeper soil moisture, grasses wets the soil surface is used more efficiently by fibrous roots than taproots. For this reason in vegetation is dominated by grasses (Herbel and Pieper, 1991; Erkovan et al., 2008). Effects of trees on grasses are cooler temperatures because of minimized evapotranspiration, leaf litter and $N_2$ fixation (Scholes and Archer, 1997). High grass productivity usually results in a large biomass accumulation combined with slow decomposition so that a large, dry fuel load accumulates. The result may be a severe fire, depending on weather patterns. But grasses can also have positive effects on these processes by providing suitable microclimatic conditions for tree and shrub seed germination and establishment (Aide and Cavalier, 1994). Environmental changes results from meristem environment by factor such as shading, water, nutrient etc. These factors changes results from morphological changes that it can be gradual or abrupt (Lawrence et al., 2003).

Fire can alter the species composition and consequently the structure, of vegetation as well as nutrient status and other attributes (Bullock, 2009; Esque et al., 2010). Different species of plants vary in their responses to fire. For example previous studies have shown that the following species were affected positively by fire; the endangered herb *Gentiana pneumonanthe*, the short-lived grass *Agrostis curtisii*, the matrix shrubs *Calluna vulgaris*, *Ulex minor* and *U. gallii*, the invasive grass *Molinia caerulea*, the invasive shrub *Cytisus scoparius* and the invasive tree *Betula pendula* (Gray, 1988; Chapman et al., 1989; Scandrett and Gimingham, 1989; Rees and Paynter, 1997; Stokes et al., 2004; Manning et al., 2004; Jacquemyn et al., 2005). The overall role of fire in species depends on population dynamics such as remove of competitor or mortality of species. Shrubs are usually more vulnerable than grasses to fire, and they may decrease competition by exposing grasses to the hazards of fire. However, fire can result in the breaking of seed dormancy, seedling growth and resprouting in shrubs that have been fire-damaged. Nano and Clarke (2010) suggested that the growth and survival of shrub seedlings dramatically decreases in the presence of adult grasses and sexual maturation may also be slow. In addition, grass competition and fire effects are important in producing shrublands-grassland mosaics. Fire can be an important disturbance in woodland or shrubland vegetation because it reduces grass cover and stimulates the germination of hard seed (Kraaij and Ward, 2006).

We planned that explain whether a demographic mechanism of shrub and grass ontogeny and coexistence can be determined. Coexistence shrub and grass during growing is advantage or disadvantage because of different growing form. We need to information how shrub and grass competition will be affected competition and fire as demographic and physiological. The role of fire on shrub and grass competition is a complex balance of positive or negative effects. We tested that how is fire affect new seedling and subsequent seedling shrub and grass ontogeny. Is there any interaction between root and shoot ontogeny and fire interact to competition these plants.

## 2. Materials and Methods

### *2.1. Experimental Design*

The experiment consisted of combinations of different aged grass and shrubs in mixtures and grown alone with 10 replicates for each combination. The ages were (young grass seedlings (YG), mature grass tussocks (MG)), shrub seedlings (YS) and older shrubs saplings (OS). The mature grass tussocks and the older shrubs saplings were grown for 1 month prior to seedlings being transplanted for the mixed treatments. These combinations were (YG-YS), (YG-OS), (MG-YS), (MG-OS) in a completely randomized design. Hence there were 8 treatments each with 10 replicates for the first stage of the experiment these plants were grown for 17 weeks during which their growth was measured. At 17 weeks the aboveground biomass was harvested of both the shrubs and the grass and second treatment applied two half replicates. A flame was applied using a propane gas burner to the cut base of both the grass tussocks and acacia stem. These plants were grown for a further 16 weeks and both above and belowground biomass harvested.

### *2.2. Plant and Soil Material*

The study was carried out under glasshouse conditions during 2010-2011 at the University of New England (Armidale-Australia). Mitchell grass (*Astrebla* sp.) and *A. farnesiana* were used in the experiment. Materials of both taxa were collected from Kirramingly Nature Reserve on 25.06.2010 according to the method of Whalley and Brown (1973). Mature tussocks of Mitchell grass were dug and placed in plastic bags and removed to glasshouse with in 12 hours where the soil was washed from the roots and the culms trimmed to about 1 cm of the bass. They left for a few days before being transplant to into pots. Acacia saplings were dug from moisture soil a placed in plastic bags and remove to the glasshouse about 12 hour and washed soil from the roots and planted into pots.

Seeds of Mitchell grass were obtained from Native Seeds Pty. Ltd, Melbourne and seeds of *A. farnesiana* were collected from Kirramingly. Ripened seeds of Mitchell grass placed in to germination trays after 1 week they were transplanted into pots with various combinations of grass and acacia plants. Seeds of acacia were scarified and placed into germination trays after 1 week they were transplanted into pots with various combinations of grass and acacia plants.

Plants were grown in 80 containers 50 cm high and 15 cm diameter filled with sand, a small amount of the soil (50 g) was applied to each pot for inoculation with *Rhizobium* bacteria by adding the soil and then watering it in. Before experiment starts, every pot was added to 20 g fertilizer (Osmocote). All pots were watered regularly on every two days by using tap water during experiment period. The pots were separated randomized in the glasshouse.

### *2.3. Plant Measurements*

Every two weeks intervals, the height of acacia and grass ligula, acaia leaf and grass stem number was measured. After harvest, shrubs and grasses were carefully separated from stem, leaves and roots and were dried for 24 h at $80^0$C for dry weight determinations. Dry mass of both of them was measured and it was used to determine of competition between grass and acacia. Grass and *Acacia* roots were carefully separated from the soil, and washed with tap water. They were dried in the oven for 24 h at $80^0$C for dry weight determinations.

### *2.4. Data Analysis*

Relative growth rate (RGR) was determined from the plant height differences at 15 days intervals fallowing by using (Ishikawa and Kachi, 2000).

$$\mathrm{RHGR} = \ln (H_2 - \ln H_1)/(t_2 - t_1) \tag{1}$$

$H_1$ is the plant or stubble height at time $t_1$ and $H_2$ the plant height at time $t_2$.

Relative neighbour effect (RNE) was determined from the dry mass following equations by using (Oksanen et al., 2006).

$$\mathrm{RNE} = (Wr - Wc)/\max(Wr, Wc) \tag{2}$$

RNE is relative neighbour effect, Wr is the performance of manipulated plants, Wc is performance of controls. This index compares the total biomass of *A. farnesiana* in the mix and with that grown as controls.

We tested before cutting and after cutting application. Grasses and acacia was growth during 17 weeks before cutting applications and than we applied to fire that the plants growth during the 16 weeks. We hypnotized firstly effects of growth ratio and relative neighbour effect in between old and young plants, before cutting application. This was tested using a two and three factor (RGR was tested three, RNE was tested two factors) ANOVA with RGR and RNE in plants height and above ground biomass. After cutting application, the first hypothesis to be tested was that burned and unburned plants had either any effect or no, and same hypothesis also to be tested was to old and young plants effects growing. In order to evaluate *A. farnesiana* responses to above and below ground ratios, height and leaves number was tested four factors ANOVA. The other hypothesis to be tested was fire and plant interactions that are effect of plant age, burned and unburned plant.

## 3. Results

Old grass tussocks had a stronger effect on acacia RGR (height growth) than younger grass seedlings after 17 weeks of growth ($F_{(1, 36)}$= 93.42, p>.0001) (Fig. 1). The growth of the older acacia saplings was more suppressed than younger acacia seedlings in competition with the old grass tussocks (Fig. 1). However, there was no interactive effect of plant age ($F_{(1, 36)}$= 1.49, p>ns). Whilst we found that old grass tussock suppressed the growth of acacia, young grass seedlings facilitated the growth of both acacia saplings and seedlings ($F_{(1, 36)}$= 5.876, p>0.0205) (Fig. 1). This was shown in the RNE where older grass tussock had a negative effect on the height growth of acacia seedlings (Fig. 2).

In contrast, the younger grass seedlings had a positive effect on the growth of acacia regardless of age ($F_{(1, 36)}$= 6.48, p>0.05) (Fig. 2).

Conversely the effect of acacia on aboveground grass biomass after 17 weeks of growth was positive when grown with older acacia saplings (Fig. 3) but the acacia seedlings suppressed grass biomass ($F_{(1, 36)}$= 29.6, p<0.001) (Fig. 3). This was shown in the RNE where young acacia suppressed the young grass but older acacia facilitated the growth of mature grass tussocks (Fig. 4). Overall there was no interactive effect of grass age and acacia age ($F_{(1, 36)}$= 1.7, p>0.1).

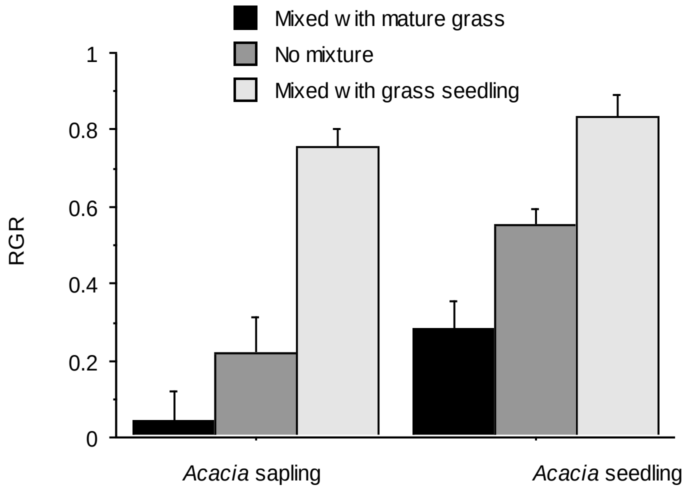

**Fig.1** Relative growth rate (height growth) of acacia in competition with old and young grass

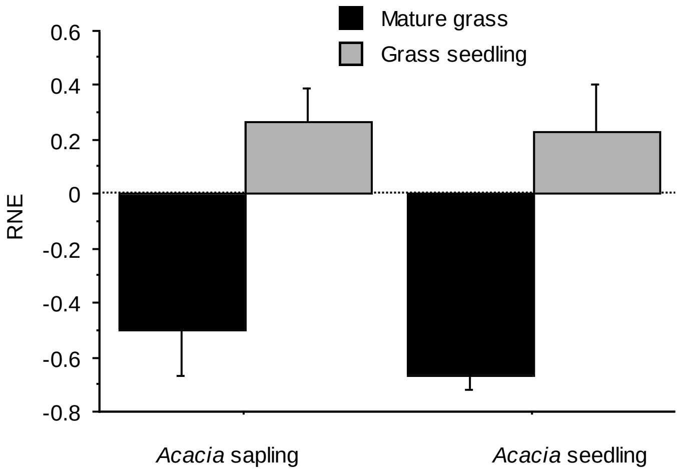

**Fig. 2** Relative neighbour effect of grass on acacia.

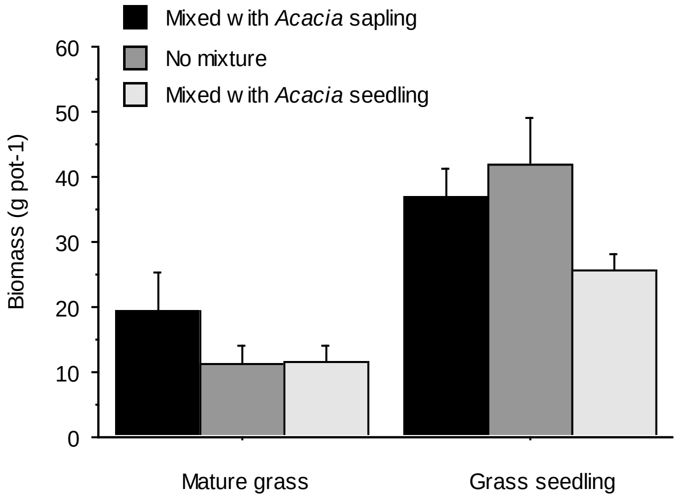

**Fig. 3** The mass of grass in competition with old and young acacia

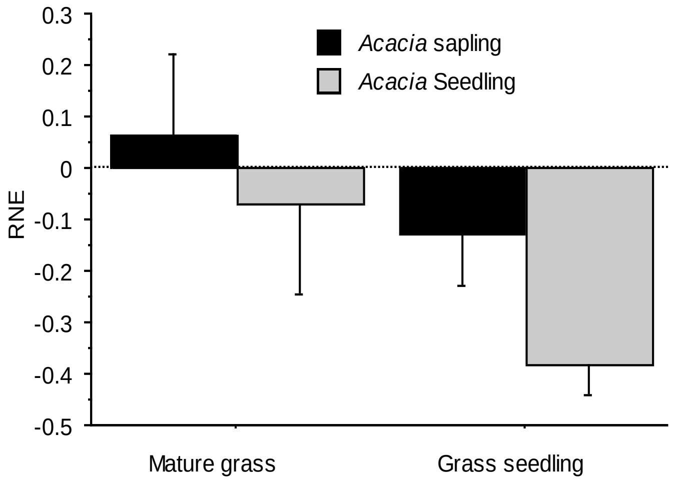

**Fig. 4** The RNE of acacia on grass growth

After remove of biomass and the application of fire there was no significant effect of fire on acacia growth variables (Table 1). The height and biomass of all acacia seedlings were negatively affected by competition with grass (Table 1), although the older acacia sapling appeared to more negatively affected (Table 1) (Fig. 5) and mature grass had a stronger effect than the younger grass tussock after 16 weeks of regrowth competition (Fig. 6). In contrast to acacia, the effects of fire on the grass tussocks were to reduce the above ground biomass of the grass (Table 2) (Fig. 7), and this was independent of grass age and acacia age. However, there was no effect of fire all the age of grass or acacia on the relative neighbour effect for total biomass (Table 2), but overall strong competitive effect of acacia on grass.

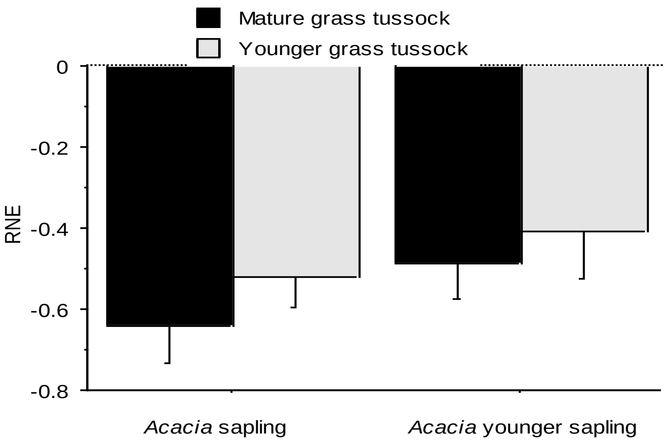

**Fig. 5** The RNE of grass on acacia after biomass removal.

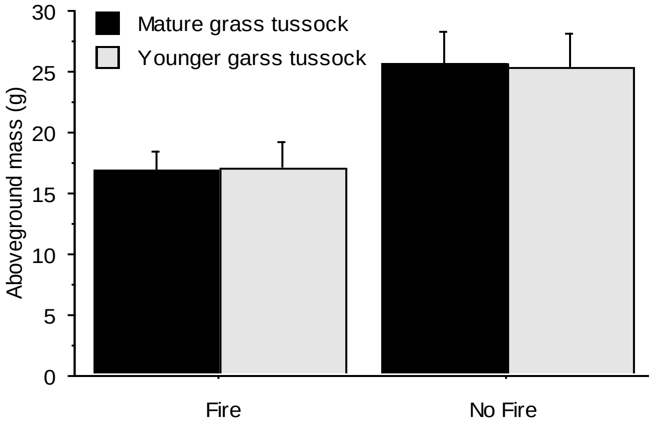

**Fig. 6** The effect of fire on grass tussock aboveground biomass

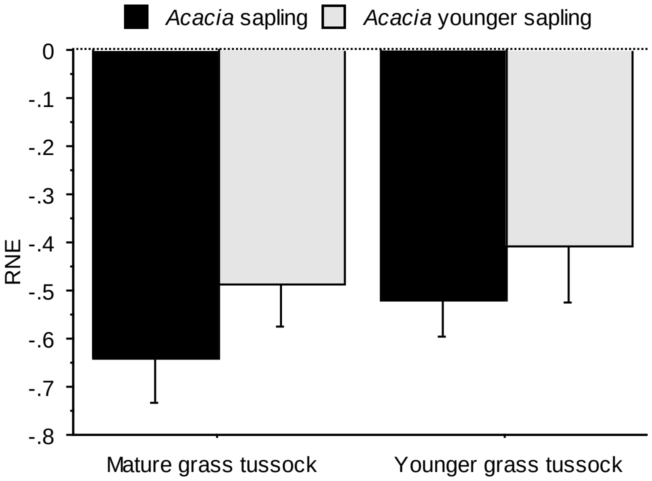

**Fig. 7** The effect of acacia and fire on grass tussock

**Table 1.** Summary results of the effect of fire and grass neighbour on acacia growth attributes.

| Factors | DF | Height | | Root length | | Aboveground Biomass | | Factors | DF | RNE | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F | *p* | F | *p* | F | *p* | | | F | *p* |
| Fire (F) | 1 | 1.62 | ns | 0.11 | ns | 2.69 | ns | Fire (F) | 1 | 0.20 | ns |
| Grass Mix (GM) | 2 | 3.86 | * | 2.00 | ns | 13.82 | *** | Grass Age (GA) | 1 | 1.423.45 | ns |
| Acacia Age (AA) | 1 | 6.76 | * | 0.33 | ns | 9.86 | ** | Acacia Age (AA) | 1 | 3.45 | ns |
| F x GM | 1 | 3.53 | * | 0.61 | ns | 2.07 | ns | F x AA | 1 | 0.74 | ns |
| F x AA | 2 | 1.45 | ns | 0.63 | ns | 0.002 | ns | F x GA | 1 | 1.57 | ns |
| GM x AA | 2 | 0.91 | ns | 0.89 | ns | 2.01 | ns | AA x GA | 1 | 0.09 | ns |
| F x GM x AA | 2 | 1.50 | ns | 0.78 | ns | 1.57 | ns | F x AA x GA | 32 | 0.01 | ns |
| Residual | 48 | | | | | | | | | | |

ns . p > 0.5, * p < 0.05. ** p < 0.01, *** p < 0.001

**Table 2.** Summary results of the effect of fire on grass growth attributes after remove.

| **Factors** | **DF** | **Root length** | | **Aboveground Biomass** | | **Factors** | **DF** | **RNE** | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | p | F | p | | | F | p |
| Fire (F) | 1 | 0.90 | ns | 19.84 | *** | Fire (F) | 1 | 0.21 | ns |
| Grass Mix (GM) | 1 | 0.13 | ns | 0.08 | ns | Grass Age (GA) | 1 | 1.12 | ns |
| Acacia Age (AA) | 2 | 0.96 | ns | 0.10 | ns | Acacia Age (AA) | 1 | 2.05 | ns |
| F x GM | 1 | 0.99 | ns | 0.02 | ns | F x GA | 1 | 1.75 | ns |
| F x AA | 2 | 0.62 | ns | 0.04 | ns | F x AA | 1 | 1.96 | ns |
| GM x AA | 2 | 1.85 | ns | 2.86 | ns | GA x AA | 1 | 0.05 | ns |
| F x GM x AA | 2 | 2.99 | ns | 9.09 | ** | F x GA x AA | 32 | 0.65 | ns |
| Residual | 48 | | | | | | | | |

ns . $p > 0.5$, * $p < 0.05$. ** $p < 0.01$, *** $p < 0.001$

## 4. Discussion

Grass shrubs relationships unknown still clearly. But the competitive, facilitative or neutral effect between grasses and shrubs relationships determines vegetation properties (Higgins et al., 2000). Plant height and biomass of acacia were significantly affected by grass mixture and acacia age (Table 1). Grasses and woody plants have reciprocal competition and have contrasting growth forms. At the beginning of the growth, grass tussocks suppressed the acacia seedling and sapling but the grass seedlings facilitated the acacia growth. This was probably due to the shade effect of lack of belowground competition. Because of different root niche, trees and/or shrubs are assumed to be able to valuable water and mineral nutrition from lower soil layers than grasses (Cramer et al., 2010). Negative effects include suppression of tree and shrub seed germination, seedling growth and survival. Tree and/or shrubs are generally accepted as ineffective competitor in the beginning of growing. Hence, grass and acacia age were affected positively plant height and biomass of acacia. Researces reported that there are positive, negative or neutral effect between grass and wody species (Ludwig et al., 2001; Riginos et al., 2009). After removing of biomass of the regrowth of acacia plants was negatively affected by grass especially the mature grass tussock. Whilst fire reduced the above ground biomass of grasses this did not affect the strong competitive performance of grass, because belowground competition was stronger. Nano and Clarke (2010) showed that shrub seedlings growth dramatically decreases in the presence of adult grasses. In addition, grass competition and fire effects are important in producing shrublands-grassland mosaics. Fire can be an important disturbance in woodland or shrubland vegetation because it reduces grass cover and increases water loss. Hence, acacia seedling or sapling growth attributes were decreases.

Grass above ground biomass was significantly affected by fire (Table 2). Grass seedlings were also negatively affected by acacia but this was less so and some facilitative effect could appears established acacia because of especially nitrogen transfer grass tussocks. The increase in grass biomass when grown with acacia saplings may be expected doe to the nitrogen fixation effect. This situation must be originated from the grass benefit nitrogen fixing ability of acacia. Because the plant has nitrogen fixation ability provide a facilitative effect on neighbour plants with grown under nitrogen poor condition (Erkovan et al. 2008). Biomass production was not significantly affected by fire after removable of biomass (Table 2). After the fire, grass biomass decreased compared to not fire. The regrowth of grass was also negatively affected by acacia especially the acacia sapling, but fire did not effect the strong competition. However, firstly after fire at the early stages of plant growth may reduce axillary bud number and viability, this condition affects plant biomass (Gullap et al., 2018). Because burned stems regrowth rapidly due to effect of nitrogen transfer to the grass from acacia growing media.

In conclusion, we have shown, that old grass tussock suppressed the growth of acacia, young grass seedlings facilitated the growth of both acacia saplings and seedlings. Older grass tussock had a negative effect on the RNE of acacia seedlings (Fig. 2). In contrast, the younger grass seedlings had a positive effect on the RNE of acacia regardless of age. After remove of biomass and the application of fire there was no significant effect on acacia seedling and sampling The effects of fire on the grass tussocks were to reduce the above ground biomass of the grass. However, there was no effect of fire all the age of grasses or acacia on the RNE for total biomass, but competitive effect of acacia on grass. Grass shrubs interactions should be investigated further, and examined as an important factor such as environment in the field or vegetation experiments.

## Acknowledgements

We thank The Scientific and Technological Research Council of Turkey (TUBITAK) for supporting to Dr. Erkovan. We also thank Dr. Knox, UNE and CMA.

## References

Aide, T.M. and j. Cavelier, 1994. Barriers to lowland tropical forest restoration in the Sierra Nevada de Santa Marta, Colombia. Restoration Ecology, 2: 219-229.

Bertness, M. and R.M. Callaway, 1994. Positive interactions in communities. Trends in Ecology and Evolution, 9: 191-193.

Breshears, D.D., P.M. Rich, F.J. Barnes, and K. Campbell, 1997. Overstory imposed heterogeneity in solar radiation and soil moisture in a semiarid woodland. Ecological Applications, 7: 1201–1215.

Bullock, J.M. 2009. A long-term study of the roles of competition and facilitation in the establishment of an invasive pine following heathland fires. Journal of Ecology, 97: 646-656.

Chapman, S.B., R.J. Rose, and R.T. Clarke, 1989. The behaviour of populations of the marsh gentian (Gentiana pneumonanthe): a modelling approach. Journal of Applied Ecology, 26: 1059–1072.

Clarke, P.J. and K.J.E. Knox, 2009. Trade-offs in resource allocation that favour resprouting affect the competitive ability of woody seedlings in grassy communities, Journal of Ecology, 97: 1374–1382.

Cramer, M.D., S.B.M. Chimphango, A. van Cauter, M.S. Waldram, and W.J. Bond, 2007. Grass competition induces N2 fixation in some species of African Acacias. Journal of Ecology, 95: 1123–1133.

Cramer, M.D., A. van Cauter, and W.J. Bond, 2010. Growth of N2-fixing African savanna Acacia species is constrained by below-ground competition with grass. Journal of Ecology, 98: 156–167.

Erkovan, H.I., M. Tan, M.B. Halitligil, and H. Kislal, 2008. Performance of white-clover grasses mixtures: Part-I Dry matter production, botanical composition, nitrogen use efficient, nitrogen rate and yield. Asian Journal of Chemistry, 20: 4071–4076.

Esque, T.C., J.P. Kaye, S.E. Eckert, L.A. DeFalco, and C.R. Tracy, 2010. Short-term soil inorganic N pulse after experimental fire alters invasive and native annual plant production in a Mojave Desert shrubland. Oecologia, 164: 253-263.

Gray, A.J. 1988. Demographic and genetic variation in a post-fire population of Agrostis curtisii. Acta Oecologia, 9: 31–41.

Gullap, M.K., S. Erkovan, H.I. Erkovan, and A. Koc, 2018. Effects of Fire on Litter, Forage Dry Matter Production, and Forage Quality in Steppe Vegetation of Eastern Anatolia, Turkey. Journal of Agricultural Science and Technology, 20: 61-70.

Herbel, C.H. and R.D. Pieper, 1991. Grazing Management. In Semiarid Lands and Deserts: Soil Resources and Reclamation (Ed. J.Skujin), Marcel Dekker, Inc., s, 361-385.

Higgins, S.I., W.J. Bond, and W.S.W. Trollope, 2000. Fire, resprouting and variability: a recipe for grass-tree coexistence in savanna. Journal of Ecology, 88: 213-229.

Ishikawa, S.I. and N. Kachi, 2000. Differential salt tolerance of two Artemisia species growing in contrasting coastal habitats. Ecological Research 15: 241-247.

Jacquemyn, H., R. Brys, and M.G. Neubert, 2005. Fire increases invasive spread of Molinia caerulea mainly through changes in demographic parameters. Ecological Applications, 15: 2097–2108.

Kraaij, T. and D. Ward, 2006. Effects of rain, fire and grazing on tree recruitment and early survival in bush-encroached savanna, South Africa. Plant Ecology, 186: 235–246.

Kurokawa, H., D.A. Peltzer, and A. Wardle, 2010. Plant traits, leaf palatability and litter decomposability for co-occurring woody species differing in invasion status and nitrogen fixation ability. Functional Ecology, 24: 513-523.

Lawrence, R., B.M. Potts, and T.G. Whitham, 2003. Relative importance of plant ontogeny, host genetic variation, and leaf age for a common herbivore. Ecology, 84: 1171-1178.

Ludwig, F., H. De Kroon, H.H.T. Prins, and F. Berendse, 2001. The effect of nutrients and shade on tree–grass interactions on an East African savanna. Journal of Vegetation Science, 12: 579–588.

Ludwig, F., T.E. Dawson, H. De Kroon, H.H.T. Prins, and F. Berendse, 2003. Hydraulic Lift in Acacia tortilis trees on an East African savanna. Oecologia, 134: 293–300.

Ludwig, F., H. De Kroon, and H.H.T. Prins, 2008. Impacts of savanna trees on forage quality for a large African herbivore. Oecologia, 155: 487–496.

Manning, P., P.D. Putwain, and N.R. Webb, 2004. Identifying and modelling the determinants of woody plant invasion of lowland heath. Journal of Ecology, 92: 868–881.

Nano, C.E.M. and P.J. Clarke, 2010. Woody-grass ratios in a grassy arid system are limited by multi-causal interactions of abiotic constraint, competition and fire. Oecologia, 162: 719-732.

Oksanen, L., M. Sammul, and M. Merike, 2006. On the indices of plant-plant competition and their pitfalls, Oikos, 112: 149-155.

Rees, M. and Q. Paynter, 1997. Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. Journal of Applied Ecology, 34: 1203–1221.

Riginos, C., B.J. Grace, D.J. Augustine, and T.P. Young, 2009. Local versus landscape-scale effects of savanna trees on grasses. Journal of Ecology, 97: 1337-1345.

Scandrett, E. and C.H. Gimingham, 1989. A model of Calluna population dynamics – the effects of varying seed and vegetative regeneration. Vegetatio, 84: 143–152.

Scholes, R.J. and S.R. Archer, 1997. Tree-grass interactions in savannas. Annual Review of Ecology and Systematics, 28: 517-544.

Stokes, K.E., A.E. Allchin, J.M. Bullock, and A.R. Watkinson, 2004. Population responses of Ulex shrubs to fire in a lowland heath community. Journal of Vegetation Science, 15: 505–514.

Treydte, A.C., I.M.A. Heitkonig, H.H.T. Prins, and F. Ludwig, 2007. Trees enhance grass quality for herbivores in African savannas. Perspect Plant Ecology Evaluation Systematic, 8: 197–205.

Whalley, R.D.B. and R.W. Brown, 1973. A method for the collection and transport of native grasses from the field to the glasshouse. Journal of Range Management, 26: 376-377.