Response of Pasture Plants to Shade in Agroforestry and Agrivoltaic Production Systems

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Abstract

Agrivoltaics production systems have gained traction globally, holding promise to supply energy and food concurrently from the same unit of land. Studies investigating shade tolerant crops to optimize production under solar panels have mostly followed the findings of agroforestry studies. However, spectral composition of transmitted radiation in agrivoltaic and agroforestry production systems may not be the same, inducing different shade responses of understory crops. A pot trial investigating the effect of shade source on biomass production and morphology of perennial ryegrass, ribwort plantain and white clover was established during spring, in Oregon, USA. Treatments were solar panel shade, hazelnut tree shade and no shade. Ryegrass plants located under tree shade were lighter (0.18 g/plant; $P<0.01$) but taller (38 cm) compared to those grown under solar panel shade (0.48 g/plant; 31 cm) and in open areas (0.59 g/plant; 13.3 cm). In contrast, 2.4 tillers/plant under tree shade were recorded compared to 5.6 and 9.2 tillers/plant under solar panel shade and open areas, respectively. Root length of ryegrass was similar in open areas (27.5 cm) and under solar panels (30.9 cm) but shorter ($P<0.01$) under tree shade (17.3 cm). Plantain grown under tree shade was taller ($P<0.01$) than under panel shade, and shortest in open areas, though having more leaves (11.3/plant; $P<0.01$) than under trees (6.6/plant) and panel shade (8.1/plant). However, plant DM weight did not differ between shade regimes ($P=0.47$). Root length of plantain grown under solar panels was longer (17.4-23.3%) than in open and tree shade areas. White clover grown under solar panels were almost 2.5 times taller than in open areas. Stolon numbers and lengths were not affected by shade treatments. Our results indicate substantial differences in shade quality induced by solar panels and hazelnut trees, thus affecting understory forages differently.

Introduction

The increasing human population has created not only a demand for greater food production, but also for an increase in available energy, and increasingly from clean energy sources. One proposed solution is to employ dual purpose land-management systems where arable land shares space with photovoltaic (PV) energy production. These dual-purpose systems are commonly referred to as agrivoltaic or agrophotovoltaic systems. Past literature has focused primarily on the selection of shade tolerant crops, which can provide similar or greater crop yields in agrivoltaic systems as in normal cropping conditions (Weselek et al., 2019). Agroforestry system findings, where crops are produced in the understory of trees, may serve as the basis for the selection of many of these shade tolerant crops. However, little research has been completed to analyze the differences in light quality between the two systems and how plant morphology might be affected. Rosati et al. (2022) found that under solar panels the spectral composition of transmitted radiation was substantially unaltered (though sometimes enriched in blue and near-UV and impoverished in red and far red), while under the tree canopy the radiation was substantially impoverished of red and enriched in far red. This could trigger different morphological responses in understory plants growing under the panels versus under the trees. The aim of this experiment was to investigate whether tree versus panel shades induce different morphological responses in understory forages, compared to full sun plants.

Methods

The study was conducted at Oregon State University (OSU) Vegetable Research Farm in Corvallis, OR in spring-summer 2022. Two sets of fifteen pots were placed within a solar array. One set was placed underneath the solar panels where direct sunlight never reached the plants, to represent the shade treatment. The second set was placed in the alleyway between rows of solar panels in a position where the plants received direct sunlight to represent the full sun treatment. A third set was placed in the alleyway between two hedgerows of young hazelnut trees, located approximately five hundred meters south of the solar array on OSU land. The hazelnut location was chosen to represent the tree cover shade condition and the pots were placed on the north side of one of the hedgerows, but near the trees, so that the pots were always under tree shade and direct sunlight never reached the plants, as was the case for pots under the panels. Each set of pots consisted of five pots each of perennial ryegrass (*Lolium perenne* L.), ribwort plantain (*Plantago lanceolata* L.), and white clover (*Trifolium repens* L.). Pots were sown on 12 May 2022. After establishment, plants were thinned to ten plants per pot, in the beginning of June when perennial ryegrass and plantain had reached first full leaf production and white clover had produced its first trifoliate leaf. Plants were then subsequently thinned to six plants per pot in late July when perennial ryegrass and plantain had reached third full leaf stage and white clover had produced a third trifoliate. In mid-August, all pots were harvested, and morphological and biomass data were collected for all six plants harvested from each pot. Insecticide was used on all pots at all locations throughout the trial in an attempt to prevent dissemination, but insect pressure was found to be too intense under the hazelnuts in regard to the white clover plants. Pots were watered regularly to prevent water stress in plants. Miracle-Gro® Pour & Feed containing 0.02% Total Nitrogen, 0.02% Available Phosphate (P_2O_5), and 0.02% Soluble Potash (K_2O) was applied to the pots every two weeks. Amount of fertilizer applied was determined according to package instructions for the size of pots used.

For perennial ryegrass plants, morphological parameters included root length (measured from the crown to the longest point of the root), plant height (measured from the crown to the tip of leaf that represented the average height of all leaves on the plant), number of tillers and leaves per plant. After recording the morphological parameters, plants were dissected and dried to a constant weight at 65°C. Plantain parameters included root length and plant height measured in the same way as for perennial ryegrass, and number of and dry matter of leaves per plant. White clover parameters included root length and plant height, again measured in the same way, and stolon number, length, and nodes per stolon.

Results and Discussion

Results from perennial ryegrass indicated that shade quality impacted morphological characteristics of the plant ($P < 0.01$), except for plant height, which was similar for the plants grown under tree and solar panels. However, perennial ryegrass plants were substantially shorter ($P < 0.01$) in the full sun conditions than shade conditions. In contrast, root length of plants was the shortest under tree shade conditions while plants grown under solar panel shade and full sun had similar root length. This is mainly due to the fact that plants in shade conditions grow taller in an attempt to make the most use of available light and plant energy reserves are reallocated towards leaf growth instead of root growth (Lin *et al*., 1988). Tiller numbers of perennial ryegrass were higher ($P<0.01$) in plants grown under full sun than other shade conditions. This can be attributed to the fact that more sun was reaching the crown of the plant, stimulating growth and tillering of the plants (Casal *et al*., 1987).

Table 1. Morphological parameters of perennial ryegrass plants grown either in open areas or under hazelnut and solar panel shade.

Parameters	Shade Treatments			SEM	P value
	Hazelnut	Solar Panels	Open		
Plant weight, g	0.18_b	0.48_a	0.59_a	0.049	0.01
Plant height, cm	38.0_a	31.0_a	13.3_b	2.30	0.01
Leaf number/plant	9.5_c	19.7_b	31.5_a	1.42	0.01
Tiller number	2.4_c	5.6_b	9.2_a	0.26	0.01
Root length, cm	17.3_b	30.9_a	27.5_a	1.94	0.01

For plantain, plants were significantly taller ($P<0.01$) under tree shade than solar panel shade condition. Similar to perennial ryegrass, plantain was shortest in full sun conditions and tallest in tree shade conditions. However, it was of note that the plantain plant weight was indifferent ($P=0.47$) to the shade conditions. Number of leaves per plant was also significantly higher for those grown in full sun than in the other shade conditions. Plant DM between solar panel shade and tree shade did not significantly differ for plantain. Unlike perennial ryegrass, plantain root length was observed to be the longest in plants grown under solar panel shade conditions than elsewhere.

Table 2. Morphological parameters of plantain plants grown either in open areas or under hazelnut and solar panel shade.

Parameters	Shade treatments			SEM	P value
	Hazelnut	Solar panels	Open		
Plant weight, g	0.47	0.48	0.59	0.078	0.47
Plant height, cm	29.4_a	19.5_b	11.5_c	0.61	0.01
Leaf number/plant	6.6_c	8.1_b	11.3_a	0.59	0.01
Root length, cm	34.0	44.3	36.6	3.11	0.09

White clover plants underneath the young hazelnut trees were decimated by insects. Between the other two shade conditions, no parameters were different except white clover plants were substantially taller in open areas than in shaded areas.

Table 3. Morphological parameters of white clover plants grown either in open areas or under hazelnut and solar panel shade.

Parameters	Shade treatments			SEM	P value
	Hazelnut*	Solar panels	Open		
Plant weight, g		1.38	1.19	0.184	0.46
Plant height, cm		9.8	25.9	1.34	0.01
Leaf number/plant		30.3	25.9	4.62	0.52
Stolon number/plant,		2.6	2.4	0.40	0.71
Stolon length, cm		23.2	19.3	4.84	0.58
Root length, cm		29.5	34.0	2.11	0.16

*Plants grown under hazelnut shade were decimated by insects.

Conclusions and/or Implications

This study shows the impact the light data findings of Rosati et al. (2022) have on the morphological characteristics of three common forage plant species. Results show that plants grown under tree shade conditions will differ to those grown under solar panel shade conditions. This is due to the fact that while solar panels alter the red/far-red ratio of light compared to full sunlight conditions, it is less impactful on plant morphology than the shade conditions created by the young hazelnut trees.

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