Effect of Stocking Rate on Forage Yield and Vegetation Management Success in Ground Mounted Solar Arrays Grazed by Sheep

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Introduction

To adhere to the Climate Leadership and Community Protection Act 2019, New York State must source 70% of its electricity from renewable sources by 2030. Up to 119,000 acres of solar could be installed, corresponding to approximately 1% of the total land available for agriculture in the state (Kochendoerfer and Thonney, 2021). With increasing community and utility scale solar installations in the US Northeast, sheep grazing has emerged as a workable strategy to manage and control vegetation in ground-mounted arrays to prevent panel shading (Kochendoerfer et al., 2019; Andrew et al., 2021). Flat and cleared agricultural land like hay and crop fields has proven to be ideal for siting, among other factors due to its proximity to access roads (Ifft, 2017). Sheep grazing allows for these lands to remain in agricultural use, while at the same time fulfilling a clear purpose. Additionally, sheep flock owners in the US Northeast are paid up to $550 per acre of fenced solar array yearly, thus greatly increasing farm viability (Grasby et al., 2021; Kochendoerfer and Thonney, 2021). However, little is known on the effects of sheep grazing management, namely yearly stocking rates and stocking densities, on vegetation management success and forage production, sheep flock health and productivity, as well as ecosystem parameters like vegetation biodiversity, pollinator habitat, and soil organic carbon sequestration in ground-mounted solar arrays. To study these effects, a multi-year, collaborative trial was designed on a 54-acre solar array adjacent to Cornell University campus. Flock health and productivity parameters, as well as forage production and quality, were studied as part of this project. The main project goal was to find optimal management strategies for sheep flocks kept on solar arrays. This project was a collaboration involving 4 Cornell University labs, (Toni DiTommaso, Soil and Crop Science, Scott McArt and John Losey, Entomology, and Johannes Lehmann, Soil and Crop Science). Each of these labs helped explore the effects of grazing density on vegetation biodiversity, pollinator habitat, predatory insect habitat, and soil organic carbon sequestration. Select methodology and preliminary results of this ongoing trial on forage production, impact of management on sheep flock health and productivity, as well as some ecosystem parameters are presented below.

Materials and Methods

All procedures involving animals were approved by the Cornell University Institutional Animal Care and Use Committee (protocol 2016-0069). A total of 136 Cornell Sheep Program Finnsheep, Dorset, East Friesian sheep and their crosses were grazed on the 54-acre, Cascadilla Community Solar Array site located adjacent to Cornell University campus. The power plant is subdivided into 5, permanently and individually fenced arrays, and was built on marginal land removed from agricultural production 10+ years ago that was brush hogged once yearly. Each of the 5 individually fenced arrays was subdivided into 6 equally sized grazing paddocks with flexible, Electronet™ fencing, excluding driveways, inverter pads, and parking areas. The fenced area within the 5 arrays was 10.3, 10.8, 4.7, 11.3, and 11.3 acres, respectively. The equally sized grazing paddocks in each array were 1.72, 1.79, 0.78, 1.89, and 1.88 acres, respectively. Each of the 30 grazing paddocks was divided into two plots that were equally sized and freely accessible by the grazing sheep. The plots were assigned randomly for the northwestern-most plot in each array, and then stratified throughout each separate array. Each plot within each paddock was either left in its natural state or broadcast frost-seeded in February 2020 with a King AgriSeeds Clover pollinator mix (White Blossom sweet clover, VNS Medium red clover, VNS yellow blossom clover, Viper Balansa clover, Dutch white clover) at the rate of 15.0 lb per acre and Pardee birdsfoot trefoil at 15.0 lb per acre. For forage sampling, each of the 60 plots were further regarded as 2 subplots, shaded areas underneath panels (and unshaded areas between the panel rows, not covered by panels), resulting in a total of 120 subplots in the experiment.

Each grazing paddock within each of the 5 arrays was randomly assigned a grazing density of 4, 8, 12, 16, and 20 sheep per acre, as well as a mowed control plot. These densities correspond to yearly stocking rates of 0.8, 1.6, 2.4, 3.2, and 4.0 sheep per acre. Grazing recommendations for non-intensively managed sheep pastures in the US Northeast range between 2 and 4 sheep per acre. The sheep were randomly assigned to a grazing density treatment each year, and they remained in their assigned density treatment throughout the grazing season. The sheep flocks were rotated throughout the 5 arrays 4 times per grazing season, with only one array being stocked at any given time, for rest periods and regrowth in all other arrays. Rest periods, depending on time of year, were 20 (early Spring), 40 (Spring and Summer), or 28 days (Fall). The total number of grazing sheep was adjusted for each differently sized array, to keep the treatment unit (grazing density in sheep per acre) intact. Data were collected between May and October in the 3 grazing seasons 2020, 2021, and 2022.

Vegetation height was assessed at 2 timepoints in the 2020 (July/August and September/October), and 3 timepoints each in the 2021, and 2022 grazing seasons (May, July/August and September/October). Vegetation height was measured and recorded in 1m^2 sampling locations in each of the 120 subplots. The sampling plots were randomly selected, and their location recorded in June 2020, and were then resampled for all subsequent assessments. These data are presented as raw averages.

Forage samples were collected at peak vegetation just prior to the sheep moving into an array, in triplicates for each of the 24 subplots. The forage inside a metal sampling frame (2.14 ft^2) randomly thrown was cut at 1.5 inch height with a RYOBI ONE+ 18V Cordless Battery Grass Shear and Shrubbery Trimmer. The samples were combined into paper bags, weighed, homogenized, and subsampled for dry matter determination. Samples were dried at 65° C in a Hotpack forage drying oven, ground in a Wiley Mill, split with a Humboldt Model H-3985 forage splitter, and frozen in 16 oz. VWR plastic containers. Forage dry matter percentage, and dry matter tons per acre were calculated. A total of n=1,427 forage yield samples were available for analysis. Data was analyzed with a mixed liner model with the *lmer* package in R (R Development Core Team, 2019).

The forage samples were pooled across array, grazing density treatment, and rotation within each grazing season, to represent the forage diet available to the grazing flock across each grazing season, for a total of 72 samples submitted for nutritional analysis at Dairy One Forage Laboratory. For completeness, a small subset of analyses results is presented as raw data.

At the beginning of each new rotation among the 5 arrays, a total of 4 times per grazing season, the grazing sheep underwent a health and condition check on site. The 5 grazing treatment flocks were body condition scored (BCS) on a 5-point scale with 1 being under conditioned and 5 being over conditioned, and assessed for haemonchosis induced anemia as parasite load indication with the 5-point FAffa MAlan CHArt (FAMACHA) scale (Bath et al., 1996), with 1 showing no observable signs of anemia, and 5 being completely anemic. A total of n = 1,038 observations were included in the dataset. Data were analyzed with a mixed liner model with the *lmer* package in R (R Development Core Team, 2019).

As part of this multi-year study, a metabolism trial was conducted at the Cornell Large Animal Research and Teaching Unit. For 3 7-day periods (2-day acclimation and 5-days sampling) in 2021 and 2022, a total pf 15 wethers (3 wethers per grazing treatment) were moved from their grazing density groups on the solar site and kept in individual metabolism stalls. During this investigation, fecal samples were collected directly from the rectum of each wether at 2 timepoints in 2021 and 3 timepoints in 2022. Eggs of the *Strongyle spp., Nematodirus*, *Strongyloides* and *Trichuris ovis* were counted with the McMaster technique (Whitlock, 1948). Occurrence of *Nematodirus*, *Strongyloides* and *Trichuris ovis* were negligeable and no subsequent analysis was performed. Eggs per grams (EPG) of feces of *Strongyle spp*. were log-transformed for analysis and back transformed for presentation, The data (n=75) were analyzed with a mixed liner model with the *lmer* package in R (R Development Core Team, 2019).

Results and Discussion

The sheep were successful in maintaining the vegetation in the solar site for the 12 and upwards grazing densities. In the 4 sheep per acre grazing treatment plots, manual string trimming along the leading edges of the panel rows had to occur. Spot trimming occurred in the 8 sheep per acre grazing density plots. For the plots grazed at 12, 16, and 20 sheep per acre density, the sheep were sufficient in preventing panel shading, and maintaining vegetation height below 18 inches of the leading panel edges, and thus no supplementary mowing or trimming was necessary (Table1).

Table 1. Average vegetation height[1].

Item		Sheep grazing density (sheep per acre)					
Plot	Subplot	Mowed control	4	8	12	16	20
Control	Unshaded	17.2	18.9	18.4	16.9	15.0	13.6
Control	Shaded	20.6	16.3	17.4	15.0	13.1	12.0
Legume	Unshaded	17.3	20.4	16.7	16.4	15.0	14.8
Legume	Shaded	23.7	17.2	16.1	14.9	13.1	11.1

[1]Data are presented as raw averages.

Notably, forage height in areas under the panels of the mowed control exceeded 18 inches, yet, even in the lowest sheep grazing density the forage below the panels was successfully maintained below 18 inches. This presents a major advantage in using sheep for vegetation management, compared to labor (and cost) intensive manual string trimming efforts in areas under the panels.

Sheep grazing density influenced forage production. (Figure 1). In both plots, Control and Legume, forage production decreased in shaded and unshaded conditions as stocking densities increased, except for yields in the Legume plot grazed at 20 sheep per acre, where yields increased compared to 16 sheep per acre in unshaded conditions.

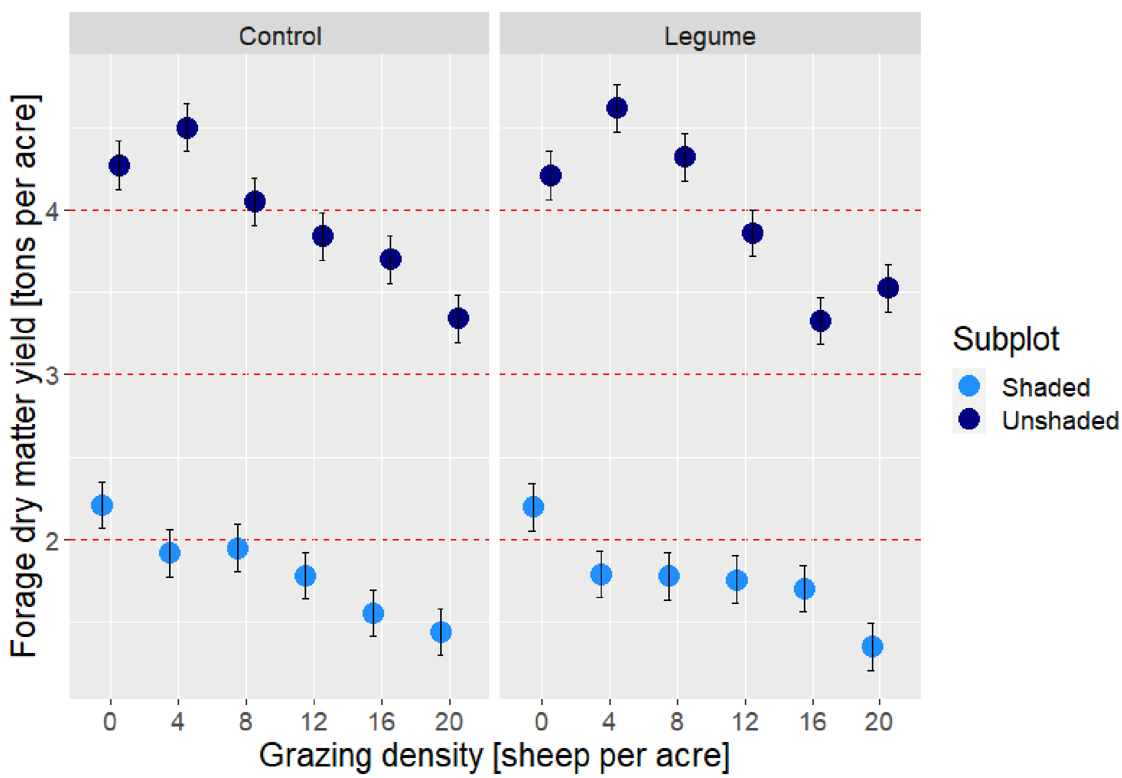

Figure 1. Total forage production for panel-shaded and unshaded areas per grazing season in 2020, 2021, and 2022.

Post-hoc pairwise comparisons were significant comparing 4 and 12, 16, and 20 sheep per acre in unshaded conditions of both plots ($p < 0.001$), and in shaded conditions for both plots comparing 4 and 20 sheep per acre ($p < 0.05$). Shade significantly influenced forage production ($p < 0.001$), resulting in up to 2.5 times less forage produced under panel-shaded conditions. This is not surprising taking into consideration the vast literature available investigating forage yield in shaded conditions (Dodd et al., 2005). Yet, these results bear considerable weight when planning grazing rotations in solar arrays. With up to 2.5 times less forage available in shaded areas underneath panels (2.5, 2.2, 2.2, 2.2, and 2.5 times for 4, 8, 12, 16, and 20 sheep per acre, respectively), and industry standards of 35 to 45% ground cover ratio (areas covered by panels), sheep farmers must adjust their yearly stocking rate to provide adequate nutrition and avoid over-grazing.

Forage dry matter (DM) percentage was not influenced by sheep grazing density but was different for panel-shaded and unshaded areas, 20.6% and 26.3% ± 0.63, respectively, ($p < 0.01$). Forage dry matter percentage increased throughout the grazing season for both plots, Control and Legume, from 23.2% to 30.9% ± 0.84 and 21.4% to 28.3% ± 0.83, respectively, ($p < 0.001$), with overall lower DM percentage for the Legume plots.

For completeness, a preliminary set of samples (n=10) submitted for forage nutritive content is presented in Table 2. below.

Table 2. Nutritional content of forage[1].

Item	Sheep grazing density (sheep per acre)				
Measured components[2]	4	8	12	16	20
CP	10.4	11.2	14.0	13.4	12.3
aNDF	58.7	53.4	51.8	55.9	60.8
NFC	20.9	25.5	24.2	20.7	16.8
Lignin	6.93	7.57	8.67	7.23	5.83
TDN	56.7	57.3	56.3	57.3	57.7

[1] Data are presented as raw averages.
[2] Forage samples were analyzed by Dairy One Feed Laboratory.

Sheep grazing density affected flock BCS and FAMACHA scores (Figure 2). With increasing stocking density, BCS decreased while FAMACHA scores increased, alluding to a loss of condition and higher haemonchosis induced anemia. The effect of stocking density on BCS was statistically significant ($p < 0.001$). Post-hoc pairwise comparisons revealed significant differences between sheep grazing in the 4, 8, and 12, grazing density compared to sheep grazing at 20 sheep per acre ($p < 0.01$). The effect of higher stocking density on FAMACHA scores trended towards significance ($p = 0.059$). Post-hoc pairwise comparison failed to produce significant differences between grazing density groups for FAMACHA scores.

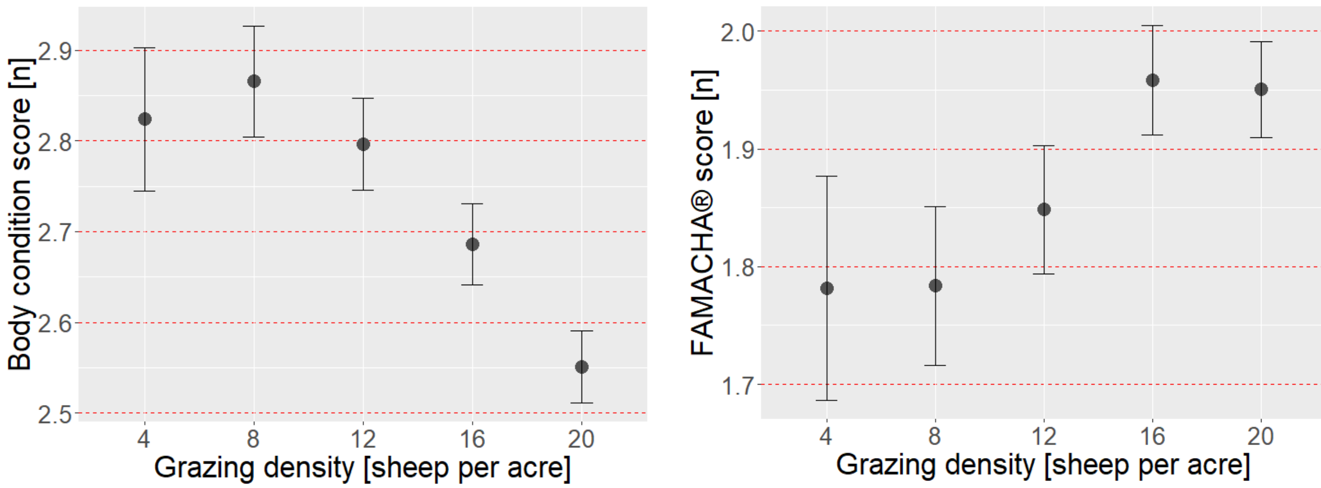

Figure 2. Body condition and FAMACHA scores.

Gastrointestinal nematode (GIN) load was low and did not clinically affect the grazing flock. Differences between 2021 and 2022 were significant ($p < 0.001$). EPG *Strongylid* GIN were 347.67, 290.23, 755.27, 1,047.59, and 643.16 ± 0.900 for the 4, 8, 12, 16, and 20 sheep per acre paddocks, respectively, and were overall too low to investigate differences in *Strongylid spp.* or further identify *haemonchus contortus* EPG. 2022 was a very dry year, the negligeable results for *Strongylid* GIN (6.51, 5.43, 14.14, 19.61, and 12.04 ± 0.852 EPG of the 4, 8, 12, 16, and 20 sheep per acre paddocks, respectively) are thus not surprising. Grazing density did not affected fecal egg counts.

Summary

Sheep grazing is a viable strategy for vegetation management in solar arrays that has the potential to increase the sheep flock in the Northeast. Solar grazing can also increase sheep farmer viability as well as lowering barriers for young and beginning farmers. Stocking densities of 12, 16, and 20 sheep per acre (corresponding to yearly stocking rates of 2.4, 3.2, and 4.0 sheep per acre) were successful in maintaining the vegetation within solar arrays built on marginal pastureland, while grazing densities between 12 and 16 sheep per acre (2.4 to 3.2 sheep per acre yearly stocking rate) may be more complementary for flock health and condition. Sheep farmers grazing solar sites should be advised to take into consideration the up to 2.5 times less forage produced in panel-shaded areas and should plan their grazing rotation accordingly.

References

Andrew, A. C., C. W. Higgins, M. A. Smallman, M. Graham, and S. Ates. 2021. Herbage Yield, Lamb Growth and Foraging Behavior in Agrivoltaic Production System. Frontiers in Sustainable Food Systems 5(Original Research) doi: 10.3389/fsufs.2021.659175

Bath, G. F., F. S. Malan, and J. A. Van Wyk. 1996. The "FAMACHA" ovine anaemia guide to assist with the control of haemonchosis. Proceedings of the 7th Annual

Congress of the Livestock Health and Production Group of the South African Veterinary Association. 5
Dodd, M. B., A. W. McGowan, I. L. Power, and B. S. Thorrold. 2005. Effects of variation in shade level, shade duration and light quality on perennial pastures. New Zealand Journal of Agricultural Research 48(4):531-543. doi: 10.1080/00288233.2005.9513686
Grasby, S., K. CAmpbell, J. Shiflett, M. MacKenzie, N. Manapol, R. McCann, L. Hain, and L. Fox. 2021. Mount Morris Agrivoltaic Study. Co-locating Solar and Agriculture at the Mount Morris Ridge Solar Energy Center., EDF Renewables, Mount Morris, NY.
Ifft, J. 2017. Large-Scale Solar Information and Research Needs for NYS, Cornell University David R. Atkinson Center for a Sustainable Future, Ithaca, NY.
Kochendoerfer, N., A. Hain, and M. Thonney. 2019. The agricultural, economic and environmental potential of co-locating utility scale solar with grazing sheep, Atkinson Center for a Sustainable Future, Cornell University Ithaca, NY.
Kochendoerfer, N., and M. L. Thonney. 2021. Grazing Sheep on Solar Sites in New York State: Opportunities and Challenges. Scope and scaling-up of the NYS sheep industry to graze ground-mounted photovoltaic arrays for vegetation management., Cornell University Atkinson Center for a Sustainable Future, Ithaca, NY.
R Development Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.
Whitlock, H. V. 1948. Some modifications of the McMaster helminth egg-counting technique apparatus. . J. Counc. Sci. Ind. Res. 21(3):177-180.