THE SOLAR GRAZING PLANNER: AN EASY-TO-USE EXTENSION TOOL FOR SHEEP PRODUCERS ROTATIONALLY GRAZING ON SOLAR SITES

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ABSTRACT

The solar energy industry is growing quickly in the United States and as it grows it takes up more land that was once used for agricultural purposes. As the human population grows and demands for food increase, solar development could mean reducing food production, while leaving vast areas of cultivatable land with unfulfilled potential. An opportunity exists to colocate agriculture and renewable energy activities. The purpose of this project was to examine the innovation of colocation strategies to support the development a useful extension tool for one such strategy. The Solar Grazing Planner is a tool designed to help sheep farmers design a grazing plan for solar-integrated sheep grazing. It currently allows farmers to calculate a stocking rate and design a grazing plan with a user-friendly Microsoft Excel worksheet. The tool is intended to benefit and support multistakeholder innovation in solar grazing and be further developed based on stakeholder feedback.

BIOGRAPHICAL SKETCH

Severin Beckwith was an environment and agriculture volunteer in Peace Corps Zambia prior to joining the Global Development M.P.S. cohort in 2020. He previously attended Clemson University where he received a B.S. in Business Management in 2016.

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Introduction

Livestock research and extension have major challenges to meet globally. Rising populations, changing diets, and climate change have become high priorities for innovation (Foley *et al.*, 2011; Mottet *et al*., 2017). Today's agriculture extension and advisory services seek to meet these challenges by facilitating access to information, knowledge, and technologies for the many stakeholders involved in agricultural activities (Birner *et al.*, 2009). Extension's goal is no longer to simply increase crop and livestock production through farmer training and the transfer of pre-developed technologies. The Agricultural Innovations Systems (AIS) perspective of development acknowledges the many actors that play a part in the process of innovation (Davis and Heemskerk, 2012).

Cornell Cooperative Extension, informed by research conducted by the Cornell University Sheep Program, is seeking to assist New York farmers and solar developers in the innovation of mutually beneficial grazing management strategies (Kochendoerfer and Thonney, 2021). Research has shown that management intensive grazing on these underused lands can have ecological and financial benefits for communities in Upstate New York (Baker *et al.*, 2014). However, academic research is only one part of a larger innovation process. Among the many actors involved in sheep production and solar development to see the benefits of innovations in livestock management, there must be interaction and participation.

This paper seeks to analyze the current state of extension and advisory services as they relate to grazing sheep on solar sites and assess future adaptation that might be made to better serve the many actors involved. The first section of this chapter will investigate existing challenges in the livestock industry and how grazing management innovations have sought to meet them. The following section will explore opportunities for the colocation of agricultural activities and solar energy production. Then, it is necessary to look at the ongoing innovations that are the focus of this paper, solar-integrated sheep grazing. Next, it will examine the stakeholders involved in such a project and specifically those with interest in solar grazing in Upstate New York. It will conclude by assessing the functions extension and advisory services currently serve in this innovation system and how they might expand in the future.

Innovations in Grazing Management

The livestock industry is growing quickly, and this growth is projected to continue over the next several decades (Mottet *et al.*, 2017). The demand for meat and milk is rising as average household income increases. Currently, over a third of the world's crop production is being allocated to animal feed; this demand will increase as household demand for meat and milk increases (Foley *et al*., 2011). Cultivated crops account for over half of animal feed and that production represents a highly inefficient way to produce food (Figure 1). On average, for a ruminant to yield 1 kg of meat it takes 2.8 kg of human-edible material (Mottet *et al.*, 2017).

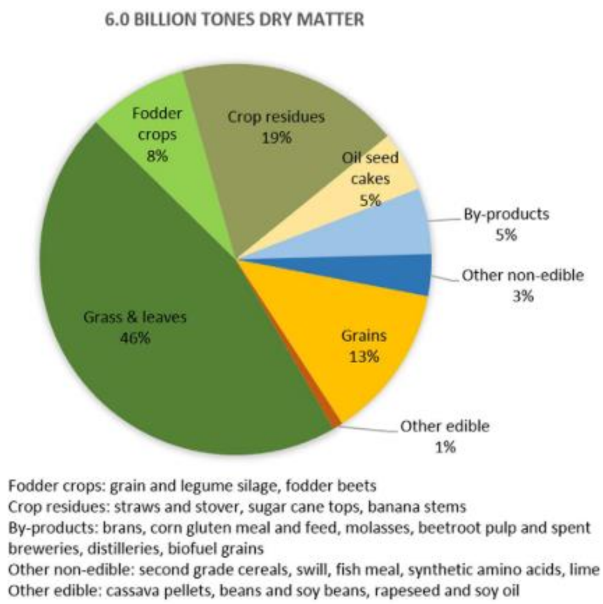


Figure 1. Global livestock feed ration. (Mottet *et al*., 2017)

The use of valuable cropland for animal feed production represents a drain on global food production. Much of the meat production seen in industrialized countries like the U.S. today is putting a heavier burden on global food systems, land use, and the environment than can be justified by their output. Cattle feedlots produce meat at a rate of 9 kg of human-edible food for every kg of meat (Mottet *et al*., 2017). These systems are environmentally unsustainable, and many scientists are calling for a shift in human diets away from such high levels of meat consumption (Foley *et al*., 2011). However, even if predictions are wrong and humans begin to consume less animal products, livestock will always be an important part of our global food systems.

As humanity faces the challenges of feeding a growing global population and doing so in an environmentally sustainable way, livestock production has come under an understandable level of scrutiny. Though the expansion of grazing land into natural habitats and the use of arable land can harm global food production and harm the environment there are still huge areas of marginal land that can be used to sustainably produce animal products. Of the 2 billion ha of grassland currently being grazed by livestock, only 684.9 million ha could realistically be converted to crop production (Mottet *et al.*, 2017).

Livestock can be a vital source of high-quality protein and micronutrients in areas where it is difficult to meet nutrient needs with only plant-based foods. In grazing or mixed systems animals are actually capable of producing more human-edible food than they consume (Mottet *et al*, 2017). Livestock can be especially important in resource-poor farming systems where they often represent a source of draught power and are of financial and cultural significance (Randolph *et al.*, 2007).

It is the goal of innovation in livestock management to balance the growing demand for animal products with the need to produce food sustainably and efficiently. Some scientists argue that sustainable intensification of marginal lands currently under livestock production will not be enough (Foley *et al.*, 2011; Smil, 2014). This may be true and despite innovations there will likely still need to be a reduction in global meat consumption, but innovations in sustainable livestock management offer a middle path between the feedlot and the vegetarian.

Compared to conventional livestock management, management-intensive-grazing (MiG) has been shown to restore marginal grasslands, reduce input costs, increase climate change resilience, and have numerous ecological benefits (Winsten *et al.*, 2010; Gosnell *et al.*, 2020; Wang *et al*., 2021). MiG is a goal-oriented management system that seeks to increase the quality of grazed lands, leaving grasslands more productive than before (Gerrish, 2004). This rotational grazing approach puts the emphasis on management rather than intensive grazing and encourages farmers to think of grazing innovation with lifestyle, financial, and environmental goals. It asks farmers to manage a balance between the nutritional requirements of their livestock and their forage supply.

In many developing nations repeated shortages of fodder for livestock cause food shortages, lost livelihoods, and damage to community relationships. Despite the clear need for innovation, case studies conducted by Ayele *et al*. (2012) in Ethiopia, Syria, and Vietnam, found significant challenges to innovation in fodder production. The study found innovation was sustainable only when linked to market activities, a network for continuous learning was built up, and interrelated innovations such as breeding and animal management were integrated.

Soil degradation is a persistent and widespread problem for farmers across Sub-Saharan Africa (SSA) (Sanchez *et al*., 1997; Mugizi and Matsumoto, 2019). A study conducted by Odadi *et al*. (2017) examined how innovations in animal management were combating this problem in the semi-arid grasslands of northern Kenya. Where traditionally nomadic cattle herding peoples have been pushed into more sedentary lifestyles the landscape has suffered. Grasslands were once given a chance to recover after being grazed, but population pressures and a government push for nomadic people to settle in permanent communities has led to drastic changes in livestock management. Planned grazing management takes lessons from existing traditional knowledge to manage modern ranches. Multiple paddocks are used to rotate cattle around the land and allow the landscape to recover in between grazing. Odadi *et al*. (2017) found notable increases in plant and animal biodiversity and increased cattle weight gain in these planned grazing systems.

Agriculture and Solar Colocation

Though Jim Gerrish, who coined the term “management-intensive-grazing”, was referring to grasses when he asked livestock farmers to think of themselves as “solar farmers first and foremost,” there are some who are beginning to approach this advice differently. When he called an acre of grassland “43,560 square feet of solar panel,” (Gerrish, 2004) Gerrish was referring to the grasses and forages that could collect this solar energy for livestock consumption, but innovations in land management and renewable energy are leading farmers to think of that “solar panel” in a more literal sense.

Colocation of utility-scale solar energy (USSE) facilities with various agriculturally beneficial activities is gaining attention with increased solar development. Walston *et al*. (2018) examined the potential for increasing pollinator habitats by improving vegetation on solar sites. The study found that nearly a million acres agricultural land in the US alone could benefit from pollinator-friendly vegetation on nearby solar sites (Fig. 2). Increased pollinator diversity and richness on solar sites offer benefits to pollinator-dependent crops like soybean, alfalfa, cotton, almonds, and citrus which make up 90% of agricultural production near USSE facilities. Solar sites may even offer ideal locations for apiaries, though research into local and honeybee preferences is ongoing (Macknick, 2019).

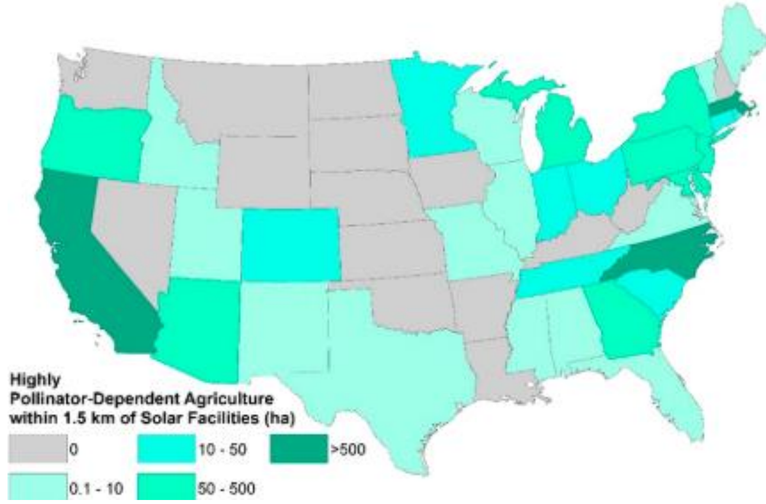


Figure 2. Amount of pollinator-dependent agriculture near USSE facilities. (Walston *et al.*, 2018)

Drylands, which make up 40% of the world's land area, are experiencing rapid development of solar energy sites (Falkenmark and Rockström, 2008; Ravi *et al*., 2016). In northwestern India, Ravi *et al*. (2016) studied the possibilities for high-value crop production on these dryland solar sites. They found that economically beneficial xerophytic crops such as *Aloe vera*, *Agave* spp., and *Opuntia* spp. could be grown on these sites without increasing land or water use. Not only can solar site and agriculture colocation offer socioeconomic benefits to rural areas by providing power and high-value crop production, but it can also have ecological benefits. Growing these drought tolerant plants on solar sites was also found to improve regional air quality by reducing dust from wind erosion.

Ravi *et al.* (2016) predicted that 250,000 ha of land would be converted to solar production by 2025 in India alone. Figure 3 shows the 2,888 existing or planned USSE facilities in the US as of 2016. Solar energy production is expanding globally, and diverse groups of innovators are developing ways to use this land for more than just energy production. Rural populations around the world still lack access to electricity, over 1.3 billion in 2017 (Guta *et al.*, 2017). Agriculture and solar colocation have shown the potential to not only provide electricity to rural communities, but also to provide economic and ecological benefits on degraded lands. However, continued innovation and stakeholder capacity building will be crucial for the sustainability of these projects.

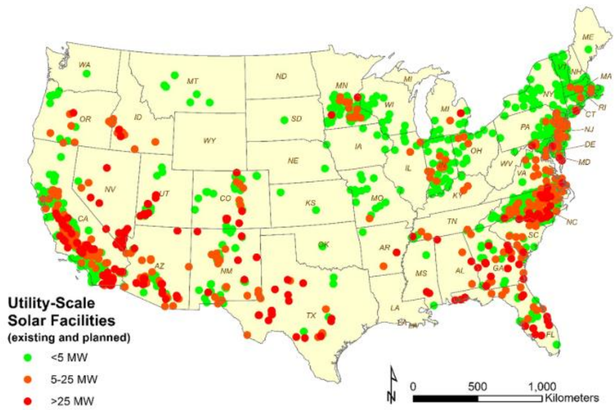


Figure 3. Existing and planned USSE facilities as of 2016. (Walston *et al.*, 2018)

Solar-integrated Sheep Grazing

Solar-integrated grazing, or just solar grazing, of livestock is just one of the ways in which solar sites can be collocated with agricultural activities. Though cattle are large enough to damage solar panels, smaller ruminants like sheep have shown promise managing vegetation on solar facility lands. Overgrown vegetation can block sunlight and reduce the energy production of solar panels which would usually call for land clearing or regular mowing. Solar-integrated sheep grazing offers a way for solar developers to manage their sites and provide a source of income for local sheep farmers, as seen in Figure 4.

Figure 4. From the left: solar site without vegetation, overgrown, and grazed by sheep. (Ifft, 2017; Kochendoerfer and Thonney, 2021)

In a solar-integrated sheep grazing operation, solar site operators offer local sheep farmers contracts which pay up to $500 per acre per year (ASGA, n.d.). Farmers are able to graze their sheep on otherwise unused land, which prevents the need to lease land to graze their sheep on or use their own land for other purposes. Sheep spend the growing season on the solar site and afterwards are either sold or housed in the farmers' facility over the winter. The farmer is thus receiving two forms of income from the vegetation management contract and animal sales.

This innovative form of land management can also have meaningful benefits for the local environment. Grazers are important regulators of grassland ecosystems and periodic grazing by migratory herbivores traditionally increased above-ground plant production (Frank *et al*., 1998). However, anthropogenic interventions in these systems by way of intensive livestock grazing can have strong negative effects on those same landscapes (Teague *et al*., 2011). Under continuous, intensive grazing many plant species can be trampled or eaten to the point of extinction (West, 1993). Loss of species biodiversity can disrupt ecosystem functions and can have widespread effects on above and belowground ecosystem biodiversity.

By putting solar sites under responsible grazing management, biodiversity can be protected and even increased (Teague *et al*., 2011). Multi-paddock grazing like that being used by solar grazers, when managed properly according to agroecological principals, has been found to have positive effects similar to those seen in natural grassland ecosystems. Highly palatable plants are not only protected from overgrazing in these systems, but they actually grow more vigorously after the periodic grazing (Zhou *et al*., 2011). Species abundance and evenness can improve under well managed systems to improve overall ecosystem function (West, 1993). On a landscape scale, solar grazing sites have the potential to increase ecosystem heterogeneity and connectivity in ways that positively affect the environment beyond the boundaries of solar facilities. These biodiversity increases can have landscape-level effects that benefit local communities and farmers that are not directly involved in solar grazing (Walston *et al.*, 2018).

Increased above-ground biodiversity is an important benefit from solar-integrated grazing, but there can be below-ground benefits as well. Increasing soil health on degraded agricultural lands could prove to be a major draw for landowners considering leasing to solar developers. Solar grazing can improve nitrogen (N) cycling and increase levels of the vital nutrient in the soil for use by soil biota and plant root uptake by stimulating growth in leguminous forages, which are capable of fixing biological nitrogen fixation (BNF) (Teague *et al.*, 2011; Paul, 2014). Carbon (C), making up about 60% of soil organic matter (SOM), is another important indicator of soil health and has substantial effects on plant production. Most agricultural soils are depleted in SOM and many climate change experts hope to decrease the amount of atmospheric CO_2 by sequestering more C in agricultural soils (Lal, 2010). C stocks have shown significant increases in soils under controlled grazing management and this effect is heavily correlated with the increased herbaceous ground cover, biomass production, and species richness.

The economic and environmental benefits of solar-integrated sheep grazing may have a lot of potential to affect farmers, solar developers, communities, and landowners, but it is still a fledgling industry. This colocation strategy is growing in popularity, but it faces many challenges. There were just 79 acres of grazed solar facilities in New York State in 2018, around 1000 acres in 2020, and up to 2000 are expected to be under contract by the end of 2021 (ASGA, n.d.). Success of such a project requires multistakeholder involvement (Guta *et al*., 2017). Farmer expertise and knowledge will need to be improved, existing extension networks will need to be expanded to meet the growing needs, market strategies for solar grazed sheep will need to be developed, and a system for matching sites and farmers will need to be implemented (Kochendoerfer and Thonney, 2021).

Solar Grazing Stakeholders

Solar-integrated sheep grazing can have benefits for many stakeholders, including the solar developers, farmers, landowners, local communities, and consumers. It is important to recognize the role of all stakeholders when considering the viability of solar development, and by extension, solar grazing on those sites.

Solar site placement is an important consideration for all stakeholders involved. Preferences for placement often differ between community stakeholders and solar developers (Ifft, 2017). Sites tend to be placed near bulk transmission lines to feed into the electrical grid. They also require road access for construction and are preferably on flat, cleared land. Sheep farmers hoping to set up a grazing contract must transport their sheep and necessary equipment to and from site which can limit the viability of distant solar facilities. Figure 5 shows areas in New York State where there are sheep farmers and transmission lines for solar sites to connect to. Site location is also important to landowners who are usually leasing the sites on long-term 25-year contracts. Community members near sites are often concerned with the aesthetics and effects on the local environment.

Introducing solar-integrated sheep grazing to solar sites would clearly benefit solar developers by providing vegetation management, but there are other less obvious benefits as well. Colocation with agricultural activities has the ability to improve local and global perceptions of solar energy as it could then offer economic and ecological benefits to the area (Ravi *et al.*, 2016; Walston *et al*., 2018; Sward *et al*., 2021). It can also allow for tax exemptions on agricultural land that would otherwise be lost by converting the land to a solar site (Ifft, 2017).

Vegetation management services on solar sites offer sheep farmers a direct source of income but can also allow them to increase their lamb production by opening up new grazing opportunities (Kochendoerfer and Thonney, 2021). As more solar sites are developed, opportunities for farmers currently raising sheep or interested in beginning to raise sheep will increase accordingly. However, farmers with sheep are not the only ones who can benefit from solar grazing in their area. The increased local biodiversity and pollinator abundance from rotationally grazed solar sites can help to improve yields and increase resilience on a landscape scale (Teague *et al*., 2011; Walston *et al*., 2018).

Landowners can sell or lease degraded land that is no longer productive for agriculture to solar developers to provide an immediate benefit, but solar grazing opens up further opportunities (Guta *et al*., 2017). Properly managed grazing lands can not only reduce erosion by increasing ground cover but can actually improve the land over time (Winsten *et al.*, 2010; Odadi *et al.*, 2017; Gosnell *et al.*, 2020). Thus, solar grazing offers landowners a use for unproductive lands and can increase the value of those lands simultaneously.

Even as global recognition of climate change and the need to switch to renewable energy sources increases solar facilities often face pushback from local communities (Sward *et al.*, 2021). This phenomenon, often labeled the “Not in my backyard” reaction, is a serious concern for developers and governments that hope to expand renewable energy production in the years to come. New York State plans to meet 50% of its electricity needs using renewable energy sources by 2030 (Ifft, 2017). Community involvement and interest in such development will be crucial for this goal to be met. There is a need for further research into how solar-integrated grazing affects community acceptance of solar development in their area, but there is reason to believe that it could have a positive impact on local perceptions.

Consumer demand for meat and animal products is on the rise globally (Foley *et al.*, 2011; Smil, 2014). Globally it is expected to exceed the upper limits of sustainable production potential by 2030. Based on these trends, demands on land for livestock production will rise accordingly (Mottet *et al.*, 2017). Though this problem extends far beyond the scope of solar-integrated grazing, colocation of small ruminant grazing and solar sites offers a way to meet some of consumers’ rising desire for animal products without increasing land use.

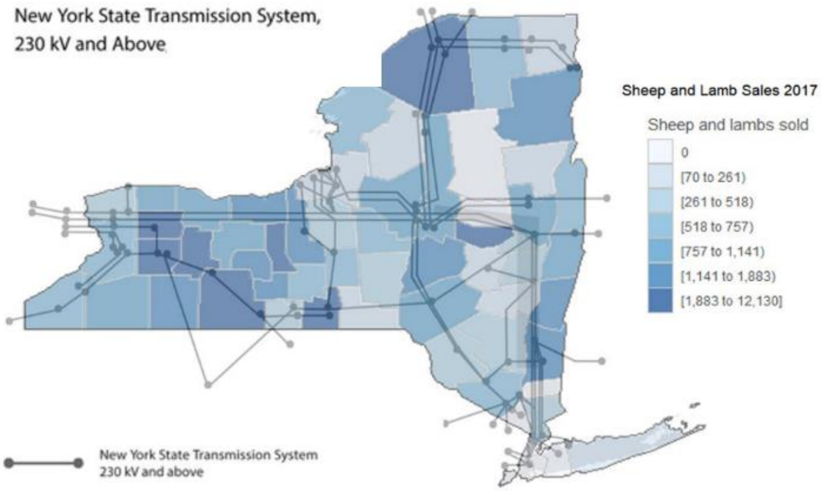


Figure 5. Transmission lines and sheep and lamb sales in New York State. (Kochendoerfer and Thonney, 2021)

Research and Extension

Recommendations for proper stocking rate and density exist for rotational grazing, but many of the impacts on the ecosystem remain little studied (Kochendoerfer and Thonney, 2021). A study being conducted by researchers at Cornell University is currently trying to determine the ideal stocking density for sheep on solar sites. They hope to find a stocking density that achieves high animal welfare, increases pollinators and pest suppressing insects, benefits diverse native vegetation, and increases carbon sequestration. This kind of research should allow future extension to recommend appropriate native vegetation, sheep breed, and other best practices for farmers and developers.

Research, though still ongoing, has shown promise for solar grazing, but for these practices to have any effect knowledge and best practices must be disseminated to stakeholders. There are currently 34 Cornell Cooperative Extension (CCE) Livestock Educators available to help farmers interested in solar grazing, but only a handful are trained in sheep production

(Kochendoerfer and Thonney, 2021). Since its creation in 2017, the American Solar Grazing Association (ASGA) has also been available to offer guidance and help match solar developers with sheep farmers (ASGA, n.d.).

Future extension will need to educate landowners, solar developers, and farmers on the benefits of leasing land, basic grazing systems, and the value of maintaining a relationship between multiple stakeholders (Baker *et al*., 2014). Further development in solar grazing is also limited by a lack of capital that can be alleviated by educating lenders and agri-businesses on the business potential for solar-integrated sheep grazing. Policy makers will also need to pass legislation to support and regulate solar grazing operations. Similar legislation for solar colocation was passed in Minnesota in 2016 to set standards for pollinator-friendly solar development (Walston *et al.*, 2018).

Extension for solar grazing stakeholders must also include market focused services. Sheep production in the US peaked in 1884 at 51 million head but has since plummeted to about 5 million in 2016 (USDA, 2020). Sheep consumption in the US has fallen from 5 pounds per capita in 1960 to around 1 pound per capita. The Northeast, due largely to its high population of Middle Eastern, Caribbean, and African consumers is a major market for lamb products, but of the sheep consumed in the US today almost half is imported. This would imply that there is a potential market for domestic sheep producers in the Northeast. Extension will need to connect farmers to existing markets and provide guidance for the development of new marketing strategies if solar grazing is to remain financially viable as it expands (Ferris *et al.*, 2014).

Conclusion

Existing innovations in livestock management have shown that if an innovation is to be sustainable, diverse stakeholders must be brought together to develop it. For solar grazing to benefit New York farmers, solar developers, landowners, and communities each group must be consulted and educated on its benefits. While university research is instrumental in establishing a scientific basis for management innovations, ultimately innovations occur amongst these stakeholders.

Solar grazing does not provide a “one-size-fits” all solution to rural livelihoods, just as solar energy cannot meet all of the world’s energy needs. Diets will need to change if global food systems are to be sustainable, but demand for animal products will never disappear entirely. Thus, it is important that meat production is ecologically sustainable and financially viable. Policy makers should support solar grazing because it offers a way for small farmers to make money, it makes efficient use of land, and it can benefit the environment. Setting local standards for best practices will ensure that solar-integrated grazing operations are managed in a way that yields the greatest benefits for the stakeholders involved.

Future research into solar grazing will need to include multistakeholder surveys and studies of market potential. Extension tools such as the Solar Grazing Planner which will be discussed in the next chapter will need to be developed for the purposes of sharing knowledge and supporting stakeholder activities. If solar energy continues to grow as expected and sheep farmers are successfully connected to grazing contracts, then sheep production will likely increase. In order for this to work two assumptions are made: first, growth must be what stakeholders want and second, there must be a market to support it. There is great potential for all stakeholders in solar colocation to benefit from solar grazing, but these benefits cannot be expected to occur until all stakeholders are involved and have access to extension tools that fit their unique needs.

CHAPTER 2: THE SOLAR GRAZING PLANNER EXTENSION TOOL

Introduction

The Solar Grazing Planner was developed to support those interested in solar-integrated sheep grazing by allowing grazing managers to determine the ideal stocking rate for a solar array. This extension tool was created using Microsoft Excel and is based on existing research in rotational grazing and, with particular emphasis, solar grazing. The worksheet can calculate the number of animals that can be kept on the land based on the user's forage sampling data, average animal weight, intended grazing intensity, and rotation schedule. This allows solar grazers to easily test out alternatives and think through management decisions to decide on the grazing plan that is best for them.

This chapter focuses on the reasoning behind the creation of this tool and how it is intended to be used. First, it will explore the background for such a worksheet and(?) the reasons which make it useful as an extension tool. Next, it will examine some of the existing livestock management tools and explore how the Grazing Planner adds to the existing toolset. Then, the focus will shift to the tool's use. This covers the sampling methods a manager might use, the management decisions the user must make before getting a stocking rate, and an explanation of the calculations which yield that stocking rate. The final section of the chapter will explore some of the possible innovations and improvements that the tool might undergo as it is further developed and tested by its users.

Background

The goal of a grazing plan is to provide farmers a tool to improve farm efficiency and encourage sustainable use of resources. The Solar Grazing Planner calculates stocking rate which is defined as the number of animals on a given amount of land over a certain period of time (Redfearn and Bidwell, 2017). It is therefore based on existing principles for rotationally grazing sheep (Lane et al., 2015). The grazing planner puts these principles to use and allows sheep farmers to assess their pasture conditions and make well-informed livestock management decisions based on that assessment. Though unpredictable elements such as rainfall variability will likely require some flexibility, solar grazers and other grazing managers using rotational grazing methods should be able to develop a custom-tailored plan with the help of this tool. These plans should include the number of paddocks to be used, rest periods for the pasture regrowth, and an appropriate number of sheep to be grazed on the land.

The Solar Grazing Planner outputs recommendations that allow mangers to design systems that ensure solar arrays are most beneficial to the stakeholders involved. If paddocks are stocked properly and animals are rotated on a well-planned schedule then farmers can experience several benefits. Pastures stocked properly benefit from fertilization, even plant species distribution, greater environmental sustainability, improved animal welfare, and more efficient production (Smith *et al*., 2011; McCarthy *et al*., 2014; Arnuti *et al*., 2020; Nedeva, 2020). Furthermore, the advantages of using a rotational grazing plan are not limited to the solar grazers. Surrounding communities and solar developers can benefit as well.

Livestock manure can be a great source of nutrients like phosphorus (P) and potassium (K), but its distribution can often be spotty, and its overall benefits reduced (Smith *et al*., 2011; Arnuti *et al*., 2020). If sheep are not properly managed the pattern of their grazing is patchy, with the animals often returning to a single patch of forage rather than grazing the full extent of a pasture (Redfearn and Bidwell, 2017). This results in a less efficient use of their manure, since the places where the animals spend most of their time end up being the places that receive most of the fertilization. The efficacy of manure fertilization is also linked to the nutrient contents which vary depending on the stage of plant growth at which grazing occurs (Gerrish, 2004). Forages are at their highest levels of nutrient content when they are in their vegetative growth stages. If grazing management allows forage plants to reach maturity the forages become lignified and nutrient content of animal excreta is reduced. When a grazing plan is well designed, animals graze on nutrient rich forage. This forage is then converted into a nutrient rich manure which fertilizes more of the pasture as animals graze more extensively. A grazing plan thus helps to ensure that pastures are grazed during their vegetative growth stages and that fertilization is evenly distributed.

Well managed pastures are also composed of more desirable plant species. It is well known that sheep have dietary preferences no less than humans and will, if given the choice, eat their favorite forage (Smith *et al*., 2011). Use of a management plan allows managers to take a larger part in grazing animals' forage selection process. When livestock grazing is limited to a paddock the animals are encouraged to graze a wider variety of plants than they would otherwise. Use of well-designed grazing plan thus results in a more even distribution of forage species and prevents desirable plants from being overtaken by low quality species (Pavlů *et al.,* 2019).

In the same vein, a grazing plan can also benefit the local ecology (Baker *et al.*, 2014). Even rotationally grazed pastures are often overgrazed, and this has negative effects on the environment as well as livestock production (McCarthy *et al*., 2014). Desirable forage species suffer with overstocking and can lead to the spread of invasive species as they gain a foothold in overgrazed pastures (Pavlů *et al.*, 2019). The effects of this have been linked to landscape-level species diversity (West, 1993).

The wellbeing of sheep is greatly affected by management decisions (Nedeva, 2020). Effective livestock managers have great influence over the health of their pastures and the animals that graze on them. A grazing plan accounts for the nutritional needs of the sheep by improving forage quality and this improves their overall health (Langlands *et al.*, 1982). Conversely, overgrazed pastures can harm livestock nutrition and health as the animals are forced to consume more toxic and coarse plant material (Mellado *et al*., 2003). Additionally, the grazing planner suggests stocking at rates which are both comfortable and fall in line with healthy social behavior (Nedeva, 2020). By defining a healthy stocking rate, the manager ensures that the sheep are physically healthy and experiencing beneficial social interaction.

Developing a grazing plan is vital for the economic success of a sheep operation. All farmers are necessarily concerned with the economic viability of their operation. A grazing plan can increase a farm's viability by making more efficient use of resources and increasing production, as can be seen in Figure 6. Improved stocking rates have long been linked to greater rates of wool growth and higher live weights (Freudenberger *et al.*, 1999). Overstocked pastures can prevent access to adequate nutrition and can harm the nutrition and overall health of the sheep (Langlands *et al.*, 1982). Pastures that are understocked, on the other hand, can decrease the efficiency of resource use and prevent farms form being financially viable (Toro-Mujica *et al*., 2011). The grazing planner helps a producer to maintain the delicate balance between undernourished animals and underutilized pastures.

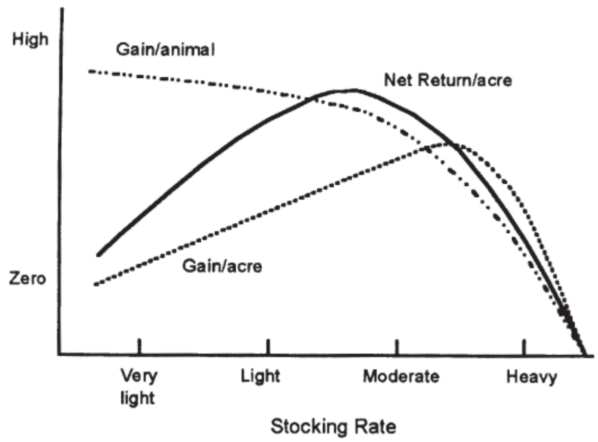


Figure 6. Weight gain of individual animal, weight gain per acre, and net return per acre as influenced by stocking rate. (Redfearn and Bidwell, 2017)

Even the solar developers and landowners can benefit from the Solar Grazing Planner. Just as understocked arrays will lead to inefficient use of forage uses, so will they lead to poor vegetation management. Spot grazing, which occurs in understocked pastures, leads to some areas being repeatedly grazed while the animals never reach others (Redfearn and Bidwell, 2017). For the solar developer, who has contracted out with a solar grazer to avoid the shading of their panels by overgrown vegetation, this kind of patchy grazing does not meet their needs. Solar developers are unlikely to hire solar grazers in the future if these are the results of their service. This, along with the environmental benefits, shows how a grazing plan can benefit more than just the solar grazer using the extension tool.

Existing Grazing Extension Tools

Other grazing plan extension tools have been created in the past with these goals in mind. Forage calculators and stocking rate worksheets have been generated by entities such as the University of Arkansas (UofA) Division of Agriculture Cooperative Extension Service and the National Resources Conservation Service (NRCS). These tools estimate the forage demand of a given number of animals of a certain weight. Using pasture information and this estimated forage demand, existing tools are able to calculate the amount of land needed for these animals.

The NRCS has developed a worksheet that allows users in New York State to create a prescribed grazing management plan. This worksheet focuses on integrated whole farm management and thus requires extensive information on everything from soil data to farm infrastructure. The breadth and depth of this worksheet allows the tool to calculate not only stocking rate, but also the frequency, intensity, and length of grazing. This is not even an exhaustive list of the calculations and recommendations that the worksheet can provide.

The plan that the NRCS worksheet allows a manager to make is extensive and no doubt highly useful in integrated farm management. There is however a drawback to the extensive and integrated nature of the plan. Not only does it require a large amount of specific information from the farmer, but it also tries to answer many questions at once. For those not seeking such a comprehensive plan the data the worksheet requires could be overwhelming. In agricultural extension, both usefulness and usability must be taken into account. As the solar grazing industry grows and expands it will require extension resources that are specific to the needs of its stakeholders. Many farmers will find the NRCS worksheet to be very useful, such as managers running mid-to-large-scale dairy farms in Upstate New York, but its usefulness differs from the needs of solar grazers.

The tool developed by UofA differs from the NRCS worksheet in that it is simple and more approachable. It seeks to answer a simple question with a small amount of information from the farmer. With a description of their herd and information on available forage the tool can calculate forage demands and acreage needed for a given herd. The worksheet has three calculators for pasture rotations, mob grazing, and strip grazing. The first calculator allows managers using traditional paddock rotation to calculate days the herd can spend in a paddock and the number of acres needed. Mob grazing uses small paddocks with relatively large numbers of animals grazing or at least trampling on every plant in a paddock within a day at most (Johnson, 2013). This helps to determine the ideal herd size and rotation schedule.. The third and final calculator defines the ideal strip size and grazing days for a strip grazing method. Strip grazing separates the pasture into thin sections using portable electric fencing (University of Kentucky, n.d.). The strip is grazed, and the fence is moved in after a short period of time.

The design of this tool draws closer to the mark for solar grazers, but it lacks applicability in some important areas. The University of Arkansas' tool, like the NRCS worksheet, contains elements of what a Solar Grazing Planner needs, but still does not fulfill all the needs of a solar grazer. For one thing, though the NRCS tool gave livestock options, this tool is designed specifically for cattle. However, it is in some ways closer to the goal of the Solar Grazing Planner.

Mob and strip grazing are both designed as high-density grazing techniques with short grazing periods (Johnson, 2013; University of Kentucky, n.d.). These techniques are likely a bad fit for someone managing a flock on a solar array which may be a long way from the farm itself. The UofA pasture rotation calculator, on the other hand, approaches the right technique for solar grazers, but it does so from the wrong direction. A solar grazer is contracting out with solar developers to graze specified plots of land and needs to be able to calculate the number of sheep necessary for a given size of land. The array may be seeded to improve the forage, but the acreage is set. Therefore, calculating acreage with a set herd is the opposite direction method than is required by solar grazers.

This new grazing planner aims to achieve the same benefits as existing tools but is rather specifically focused on the needs of solar grazers. While the existing tools are useful for many livestock managers, the focus is not directed at sheep solar grazers and this is reflected in their design. The Solar Grazing Planner, designed with solar grazers in mind, fills in some of the gaps in what existing extension tools have to offer. Furthermore, it ought to be continually developed with the needs of solar grazing stakeholders in mind.

Sampling

The first step in calculating the appropriate stocking rate is to sample the forage that the sheep will be grazing. The goal is to estimate the overall biomass of the pasture and there are a number of ways that a farmer might go about this (Lane *et al.*, 2015; Rayburn and Lozier, 2016). Sampling methods vary widely in the equipment they require and their accuracy. Techniques range from something as rudimentary as a “visual appraisal” to the use of a sophisticated electronic probe device. Though some of the methods provide a much rougher estimation, these methods are still widely used by farmers and the Solar Grazing Planner accounts for this.

One common type of technique for estimating pasture forage quantity is to use the height of the pasture (Rayburn and Lozier, 2016). Height, though correlated with overall biomass is not the only factor that determines pasture mass. Techniques that use height will provide a rougher estimate than clipping, which is the standard for scientific studies. The “Pasture Height” sampling option in the solar grazing tool, seen in Figure 7, is based on recommendations made by the West Virginia University Extension Service. It allows farmers to calculate the dry matter per acre of their paddocks using either a ruler, a falling plate meter, or a Farm Tracker rising height meter. Farmers take their height measurements and estimate the density of the pasture, as either “Thin”, “Average”, or “Thick”, to find the approximate dry matter per acre. For solar grazers it may also be advisable to average their results from forage measured between the solar panels and those measured beneath. Averaging the two will provide a dry matter value which is more representative of the forage growing across the entire paddock.

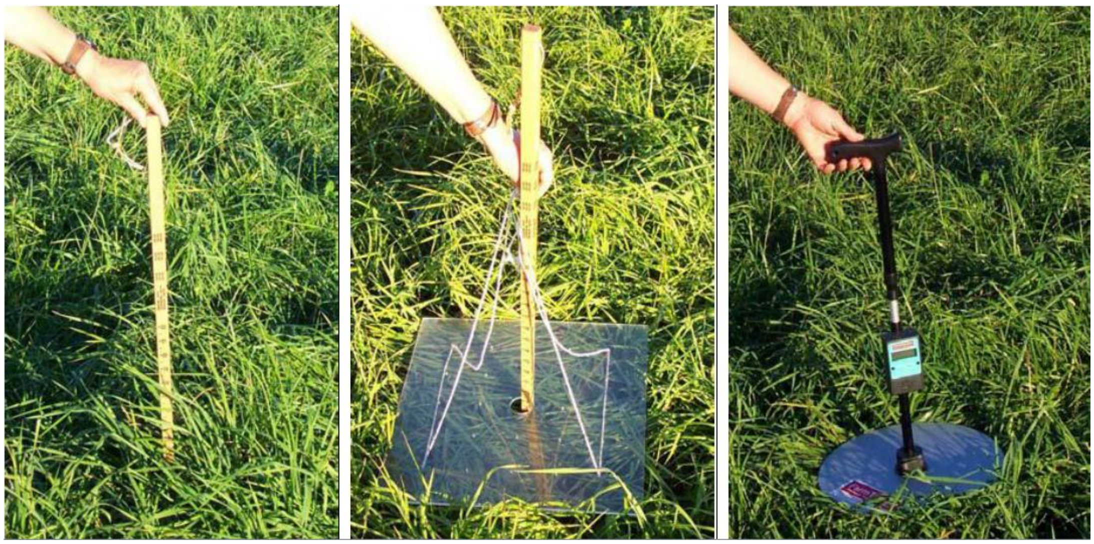


Figure 7. From the left: Ruler, falling plate meter, and Farm Tracker rising height meter measurement methods. (Rayburn and Lozier, 2016)

A more accurate method of estimating pasture biomass is to clip a sample of the forage using a frame. A depiction of this method can be seen in Figure 8. The farmer should know the measurements of the frame and based on the weight of their sample, should be able to calculate biomass per acre. It can also be made more accurate for solar grazers, similar to the recommendation for those using the height method, by taking samples from between and underneath the solar panels. Due to varying levels of water in the sample, fresh weight alone will not tell the farmer their dry matter per acre. Many farmers simply use a standard dry matter percentage and the wet weight to gauge the total pasture mass ("Pasture Inventory: How to," 2018). The sample can also be dried in the oven and weighed a second time to yield a dry matter percentage. Though this method is more tedious and requires more equipment than other sampling methods, it is the most accurate. To reflect the diversity of sampling methods used, the grazing planning tool allows managers to use either a standard dry matter percentage or and oven dry weight.

Figure 8. Farmer using the clip and weigh sampling method. (Barnhart, 2009)

Though the pasture gauge is not included in the Solar Grazing Plan at this time, the electronic probe device does offer another possible sampling method. The probe, which looks like a walking stick, is used to take 25-30 digital readings of a paddock. It will then return the average total mass of the pasture (Lane et al., 2015). Managers using this method can simply input the reading manually into the grazing planner.

Another method not included in the Solar Grazing Planner is the “visual appraisal”. Though some experts are likely capable of making reliable estimates this method is generally not very accurate (Barnhart, 2009). It relies on an eye-ball assessment of the paddock in question and a “feel” for the forage mass present in the pasture. If managers prefer this method they can enter their estimate manually as with the pasture gauge reading.

Choosing a Management Strategy

Aside from sampling their paddocks, farmers must also make a few management decisions in order to calculate their stocking rate using the Solar Grazing Plan. First, farmers should have an idea of how many paddocks they wish to break the array up into. Then they should have an idea of how intensely they want to graze their paddocks. This decision is reflected in the refusals percentage chosen. The refusals percentage is how much residual forage will remain in the paddock at time that the sheep are rotated. Finally, they will need to decide how long the paddocks should be allowed to rest between grazing periods.

The rest period is a crucial part of rotational grazing management. Plants growing in pastures that are grazed continuously do not have the regrowth and recovery time necessary for them to flourish (Gerrish, 2004). If the forages are not given a chance to store carbohydrates and develop roots then pasture quality will suffer accordingly. However, this rest period must be carefully timed so as to prevent plants from maturing and becoming lignified. Older plant tissues are less palatable and less nutritious. The right rest period varies by season, weather conditions, and forage species present in the pasture.

Though forage quality is the biggest driver behind a producer's rotation schedule, rest periods can also be effective ways to manage internal parasites. Rotating sheep can disrupt the lifecycles of major parasites such as barber's pole worm (*Haemonchus contortus*), the lifecycle of which is depicted in Figure 9 (Colvin *et al.*, 2008). Sheep infected with large numbers of this nematode parasite commonly suffer from anemia, weight loss, and poor fleece quality (Crilly *et al.*, 2020). Managing these parasites, and others like them, is crucial for the animals' health and the economic viability of the farm. Barber's pole worm matures in the feces of the animals and migrate onto forage that sheep will then ingest. In colder regions it can require long rest periods to significantly reduce the population, but some managers in cooler climates have had success in this way (Colvin *et al.*, 2008). Ultimately, managers are left with a lot of factors to weigh in their calculation of a rotation schedule.

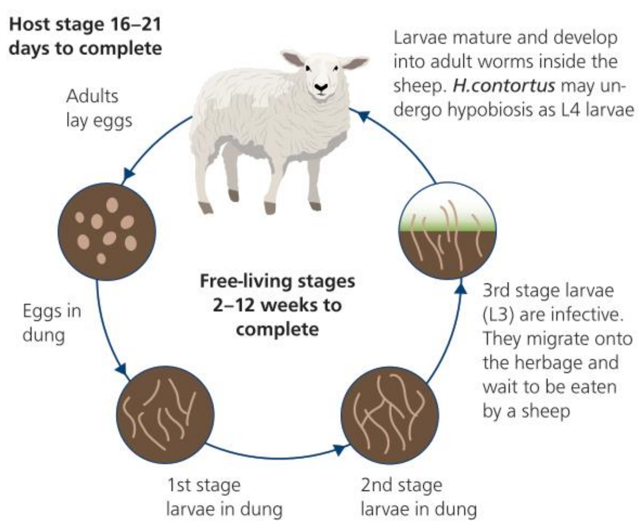


Figure 9. The basic lifecycle of the barber's pole worm. (Crilly *et al.*, 2020)

Well planned rest periods are crucial for effective use of the grazing planning tool, but the number of paddocks a farmer intends to use and the intensity with which they hope to graze them are tightly linked to this decision. If all else stays the same, stocking density will increase as the number of paddocks increases. This stocking density can have strong effects on pasture recovery.

Forage regrowth is essentially a function of current photosynthesis so the Leaf Area Index (LAI), or the area of canopy cover per area of ground surface area, has clear influence on a pasture's recovery (King *et al*., 1979). Repeated defoliation under high stocking densities, especially with long grazing periods, can thus inhibit regrowth of valuable forage. Managers must plan choose a number of paddocks, and thus a stocking density, that balances efficient use of forage growing in the pasture without preventing adequate regrowth for the next rotation.

The stocking density, like the rotation schedule, a manager chooses can vary widely. Using a higher number of smaller paddocks has been shown to allow for more intensive rotational grazing with higher stocking rates (Barnes *et al*., 2008). However, the exact stocking density a producer chooses to use, similar to rest period length, depends on their own goals and pasture conditions (Gerrish, 2004).

The refusal percentage is important to the Solar Grazing Planner because sheep will not consume all biomass present in a paddock even in the most intensive grazing strategy. There will always be a portion of the plant biomass that is unpalatable, and some will also need to be saved to allow the plants to recover during the rest period. Managers must therefore plan to rotate their animals in time to leave enough residual biomass to maintain a healthy and productive pasture (Smith *et al*., 2011). Figure 10 shows the effect that different grazing intensities can have on forage regrowth. The refusal percentage that producers choose in the Solar Grazing Planner represents this unconsumed plant matter left in the paddock after the sheep are moved.

Figure 10. Orchard grass (*Dactylis glomerata*), clipped to either 1 inch (left) or 3.5 inches (right) shown after 6 days of regrowth. (Smith *et al*., 2011)

Managers sampling by forage height often decide their level of residuals based on height as well (Szymczak *et al*., 2021). The refusal percentage allows producers to calculate the amount of biomass that will be left behind based on height after grazing. However, farmers that choose to use the clipping sampling method will often only clip down as far as the desired height and thus skip this step. They will need to estimate the amount of plant matter in the sample which is unpalatable and will thus be refused by the sheep to get their refusal percentage. As with the other management decisions, this percentage will vary. Managers must have a keen awareness of what the animals will eat and how much must be left behind for the continued health of the pasture. The grazing plan tool can help them prepare for this and stock accordingly.

Access to the Solar Grazing Planner does not excuse producers from being well informed on grazing best practices and they will need to put careful consideration into their management decisions. There are currently no calculations to determine these values in the Solar Grazing Planner, but it is easy to modify strategy decisions to view their effects on the grazing plan. This can help managers think through their best options when weighing these critical decisions.

Calculating Stocking Rate

With the management strategy chosen and paddock information entered, the grazing plan tool can then calculate the stocking rate per acre. A series of simple calculations based on the available forage, grazing intensity, rest period, and sheep production standards can inform the producer on the correct number of animals to graze on their land. The stocking rate that the grazing plan yields, when coupled with accurate sampling data and well-informed management choices, has the potential to be highly valuable to producers that choose to use this tool.

By the time the stocking rate is calculated, the manager has decided the number of days for their rest period and the number of paddocks that will be used. The number of days the animals will spend in each paddock is thus the rest period divided by the one less than the total number of paddocks. This is the length of time the existing forage biomass will need to support the flock before it is given a chance to regrow.

No paddock is completely covered in vegetation, as there are always some areas sacrificed for other purposes. A solar site with many rows of panels built into the paddock can obviously not be entirely covered by vegetation, but even a traditional pasture will have high traffic areas such as watering locations and access gates. The amount of forage available over the days in the paddock will thus be reduced to match the actual acreage under vegetation.

The dry matter in the paddock must also be reduced to the amount that will actually be consumed. The refusal percentage must be deducted from the dry matter total for the reasons mentioned in the previous section. The correct stocking rate will mean that all of this dry matter which remains after accounting for refusals will be consumed over the number of days that the flock is to be in the paddock.

In order to calculate the stocking rate for a paddock over a period of time the calculation must assume the amount of dry matter that the sheep will consume in a day. The standard value for daily dry matter intake in sheep is 3.5% of their body weight (Lane *et al.*, 2015). With the average weight of the flock, this standard intake can give a manager a reasonable estimate of the amount of dry matter the flock will consume in a day.

The total available dry matter in the paddock divided by that consumed in a day by a single animal will give the number of animals that could be supported on it for a day. Since the plan assumes that the total acreage must support these animals for an entire rotation cycle the final number of animals to be grazed on the land will be that value divided by the length of the rest period, or one rotation. The stocking rate per acre is simply the total number of sheep divided by the total acreage.

These calculations are simple and based on established rotational grazing principles. Their greatest advantage to the manager is therefore to allow them to form these established principles into a grazing plan through a clear and easy-to-use worksheet. A producer can test out various management strategies using the tool and save plans which they want to refer to later. The grazing manager can thus run through multiple alternatives to find the plan that best suits the goals of their operation. By displaying the plan in a clear format, the tool can support the thought process behind management decisions within a season or over multiple seasons.

Ongoing Solar Grazing Research

Previously developed grazing planning tools have failed to meet the specific needs of solar grazers because grazing on a solar site has some significant effects on how forage ought to be calculated. On a solar sight, sunlight available for pasture growth is heavily dependent upon whether the spot is shaded by panels or not. Constant shading by rows of solar panels is going to change the makeup of forage available for grazing animals.

Calculating the difference between shaded and nonshaded portions of the pasture on solar sites is going to be crucial to making the Solar Grazing Planner effective for solar grazers, but this is a new area of research. Researchers at Cornell University have been conducting a solar grazing study which, though ongoing, can provide some insights into forage growth patterns on solar sites (Kochendoerfer *et al*., 2021). As one can observe in the experimental design displayed in Figure 11, the study has divided solar arrays into six paddocks, each stocked at a different rate. Each paddock was then further subdivided into half which was legume seeded and half which was grass seeded.

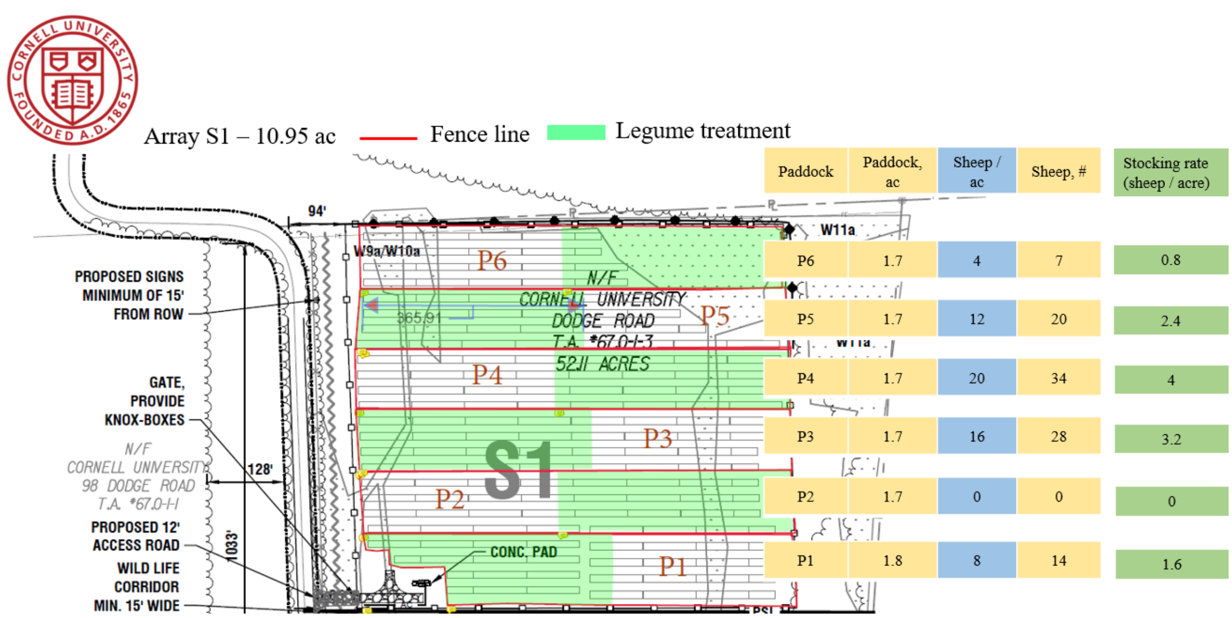


Figure 11. Experimental Design for Cornell University Sheep Program Solar Grazing Study (Kochendoerfer *et al*., 2021)

During the grazing season, the five solar arrays being used for the study are sampled at the beginning of each rotation (Kochendoerfer *et al*., 2021). Samples are taken both between and underneath the solar panel rows using clippers and a frame. Figure 12 depicts the sampling areas with the highlighted area representing the legume treated half of the paddock and lines showing the bounds of the “not under” sampling area. Samples are taken for each seeding treatment and subplot, not under and under, yielding four forage samples per paddock.

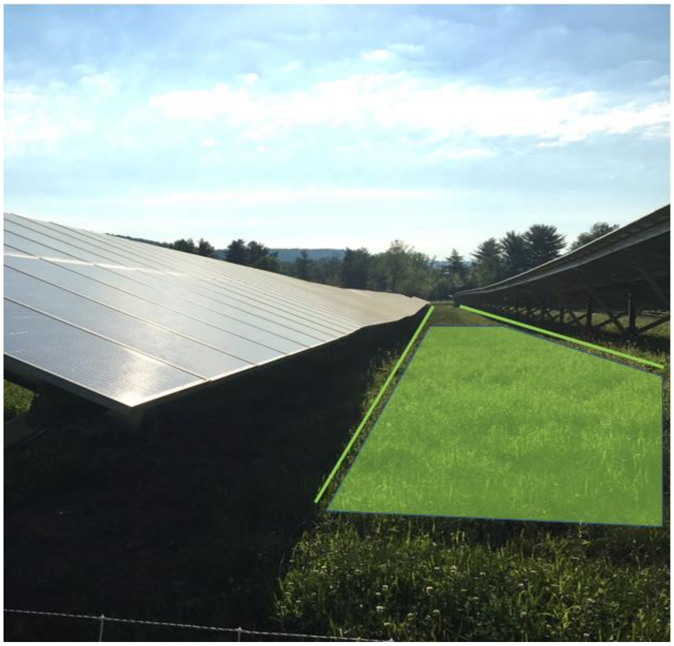


Figure 12. Sampling area used by Cornell University study (Kochendoerfer *et al*., 2021)

Preliminary data from this forage sampling has shown significant variation in forage DM quantity across the four rotations within the season (Kochendoerfer *et al*, 2021). DM in metric tons per hectare (DMtha) ranged from an average of 0.192 DMtha at the beginning of the season to 1.181 DMtha at the fourth rotation. This is important to the Solar Grazing Planner because it suggest, as would be expected, that forage quantity will fluctuate within a growing season. This data also indicates that if managers calculate a stocking rate based on spring sampling they can be confident that enough forage will be growing in the pasture as the season progresses.

Significant variation in forage DM quantity between and under the solar panel rows has also been found in preliminary data (Kochendoerfer *et al*., 2021). Samples from areas not under the panels averaged 0.707 DMtha and underneath averaged 0.397 DMtha. There was, on average, 43.8% more forage growing between the rows than underneath the panels. This is a clear sign of the importance of a solar site-specific grazing planning tool. To reach its full potential as an extension tool the Solar Grazing Planner will need to incorporate data from studies like this to better inform stocking rate decisions. Currently, managers would need to sample between and below rows to get a representative sample of forage in their pasture, but with enough data the Solar Grazing Planner could make useful estimates of total forage quantity with less information from the user.

Information garnered from this study, and future studies like it, will allow the Solar Grazing Planner to include calculations for DM changes throughout the season and across entire solar arrays with only one sample from a solar grazer. If the Solar Grazing Planner is developed alongside future research, it can improve the quality of calculations made and become easier to use without sacrificing the accuracy of its recommendations.

Conclusion

The Solar Grazing Planner as it exists now is useful and approachable for solar grazers. However, it has room to improve as more research is conducted to inform on solar grazing decision making. At the same time, it should expand to meet the needs expressed by producers and other stakeholders. Further development of the tool will likely fall into the areas of ease-of-use, support for additional sampling methods, improved tools for developing management strategy, and stakeholder driven innovations. The goal of the tool is to align with the needs of solar grazers and proper alignment will require feedback from its intended users.

The grazing plan has been developed in an academic setting and thus its ultimate test lies ahead. If active and aspiring solar grazers are able to make use of the tool then it will have achieved its first goal, but its usability can likely be improved after it has been in the hands of farmers. As was discussed in the case of the NRCS worksheet, a tool can be very useful to some, but can be overwhelming or difficult to use for others. Quality of life improvements can be made to add necessary instructions, streamline worksheet functions, and generally make the tool more approachable to the average user.

When discussing the sampling methods supported by the Solar Grazing Planner only a few of the many possible sampling techniques were included. Popular and widely accepted methods are included, but this may not meet the expectations of all users. If significant numbers of solar grazers prefer an additional sampling option this ought to be added. The Solar Grazing Planner should be able to make accurate estimates with the sampling information given, so more accurate methods are preferred, but it may need to compromise in favor of usability in some respects.

Currently, the Solar Grazing Planner requires managers to make some strategy decisions on their own. The tool could be expanded to include calculations for management decisions such as rest periods if there is a demand for it. In the case of those without a clear strategy, it could provide additional planning benefits. This would require more information from the user but could be made optional to streamline calculations for those users who have a pre-existing strategy in mind.

Ultimately, feedback from stakeholders should determine the course of future innovation of the Solar Grazing Planner. It must continue to rely on sound scientific principles while adjusting to meet the needs of those it is meant to benefit. Some of their suggestions will likely fall in line with the expected improvements previously mentioned, but unexpected requests will probably arise as well. If this worksheet is to be successful as an extension tool, it must be open to feedback from all of the stakeholders involved in solar grazing.

APPENDIX A: The Solar Grazing Planner

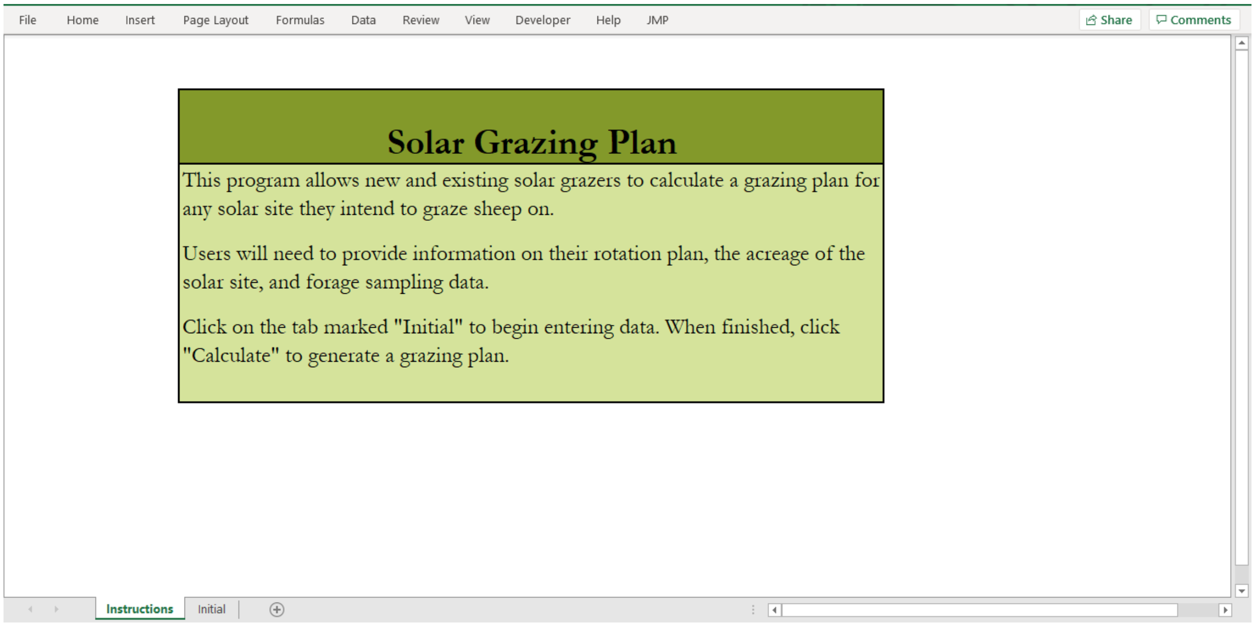


Figure A1. Solar Grazing Plan instructions tab

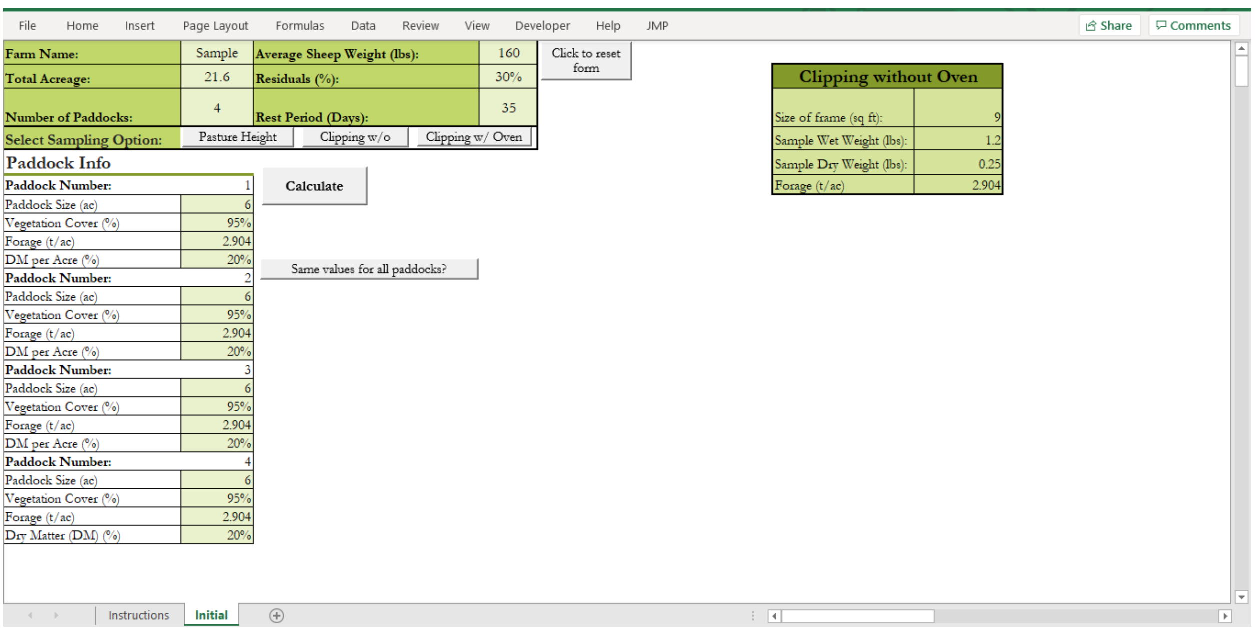
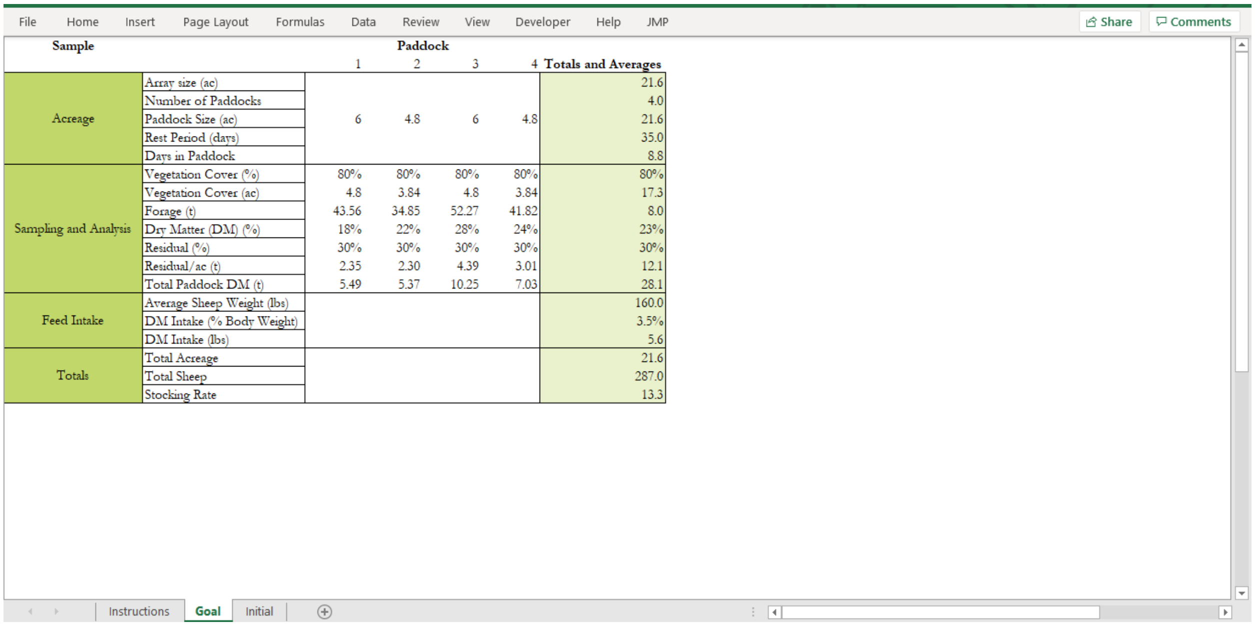


Figure A2. Solar Grazing Plan sampling and farm information tab



Sample		Paddock 1	2	3	4	Totals and Averages
Acreage	Array size (ac)					21.6
	Number of Paddocks					4.0
	Paddock Size (ac)	6	4.8	6	4.8	21.6
	Rest Period (days)					35.0
	Days in Paddock					8.8
Sampling and Analysis	Vegetation Cover (%)	80%	80%	80%	80%	80%
	Vegetation Cover (ac)	4.8	3.84	4.8	3.84	17.3
	Forage (t)	43.56	34.85	52.27	41.82	8.0
	Dry Matter (DM) (%)	18%	22%	28%	24%	23%
	Residual (%)	30%	30%	30%	30%	30%
	Residual/ac (t)	2.35	2.30	4.39	3.01	12.1
	Total Paddock DM (t)	5.49	5.37	10.25	7.03	28.1
Feed Intake	Average Sheep Weight (lbs)					160.0
	DM Intake (% Body Weight)					3.5%
	DM Intake (lbs)					5.6
Totals	Total Acreage					21.6
	Total Sheep					287.0
	Stocking Rate					13.3

Figure A3. Solar Grazing Plan calculation tab

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