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Creating new foodscapes to enhance the sustainability of rangelands in the Western U.S.

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Abstract

Approximately eight million beef calves are produced annually in the western U.S., and ranchers must maintain profitable operations while addressing the growing number of consumers seeking environmentally, economically, and socially sustainable food. In response to such challenges, a diversity of deep-rooted perennial legumes and non-legume forbs high in nutrients and functional phytochemicals, are being grown and stockpiled in resource patches or “islands” across a “sea” of grass-dominated rangelands. These islands of multifunctional diversity are being tested across monotonous landscapes to be used as a low-cost and sustainable supplementation strategy for beef cattle with the aims of increasing biodiversity, animal productivity and health, while reducing environmental impacts. We are screening native and introduced plant species for their establishment and persistence in replicated studies at different ecosites in northern, central and southern Utah. Continuous culture fermenters are being used to evaluate how these forages and their combinations alter rumen fermentation, microbial growth, methane production, and nutrient digestibility. These forages are being strategically deployed in islands across the landscape aiming at higher probabilities for seedling success. This research is being integrated at the regional and local level through grazing schools, demonstration sites, and assessments of potential for adoption through online surveys and subsequent semi-structured in-depth interviews. This transdisciplinary project is progressing to create more sustainable beef production systems while engaging and educating a wide range of stakeholders including current and future land stewards, outreach personnel, and consumers.

Introduction

Approximately eight million beef calves are produced annually in the western U.S. alone (NASS 2024), and beef producers must maintain profitable operations while addressing growing consumer demands for environmentally, economically, and socially sustainable food (Villalba et al. 2019). Under this context, we are developing a transformative paradigm for western U.S. beef production systems through landscape interventions -smart foodscapes (SFS)- in order to increase American agricultural production with a reduction in environmental footprint. Our reasoning for this project stems from the idea that cattle evolved in the Mediterranean region grazing a diverse palette of broadleaf and grass species (Grove and Rackham 2001), but cowherds grazing U.S. rangelands today consume a diet dominated by a monotony of grasses like intermediate, tall and crested wheatgrass (Robins et al. 2020). The feeding value of these grasses plummets in mid-summer, disrupting nutrient cycles and necessitating costly supplementation (Putnam and DelCurto 2020). In turn, declines in the nutritional quality of grasses cause significant increments in the production of the greenhouse gas (GHG) methane by livestock (Lee et al. 2017). Legumes and some forbs are of greater nutritional value than grasses (Phelan et al. 2015), and, unlike grasses, many of these species also contain functional biochemicals or plant secondary compounds (PSC) (e.g., phenolics, terpenoids) that enhance cow-herd health and decrease nitrogen and GHG emissions to the atmosphere (Min et al. 2020). In addition, islands of diversity have the potential to increase landscape connectivity and structural complexity in rangelands, enhancing ecosystem biodiversity and resilience (Leroy et al. 2020). We are creating multifunctional alternative foodscapes using strategically selected legume and non-legume forb species (Objective 1), that synergize nutritionally (Objective 2), and are spatially distributed as resource patches or islands of diversity across the landscape (Objective 3), solving these key challenges to current and future food and agricultural production systems. This research is being integrated at the regional and local level through producer engagement and assessments of adoption (Objective 4).

Methods

Objective 1. The establishment and persistence of two dozen plant species with the potential to provide late-season supplemental protein when seeded as "resource islands" was assessed in strategic locations across semi-arid rangeland. The species include crested wheatgrass and native and introduced legumes and non-legume forbs, with excellent forage value, that are commonly included in rangeland grazing or restoration seed mixtures. Replicated monoculture plots were drilled at four rangeland locations from 1370-2000 m a.s.l. in northern, central and southern Utah in 2022. In July 2023, establishment was assessed as plants m^{-2}, although monoculture plots ranged from 11 to 74 m^2 depending on location. Average annual precipitation, primarily as snowfall, ranges between 247 and 457 mm $year^{-1}$.

Objective 2. Our objective was to evaluate the effect of potential forage candidates for the "islands" on rumen fermentation. The study was conducted as a 5 × 5 Latin square design using continuous-culture fermenters. All treatments contained 75% of crested wheatgrass plus (1) 25% alfalfa, (2) 25% sainfoin, (3) 25% small burnet, (4) 12.5% sainfoin + 12.5% small burnet, and (5) 8.3% sainfoin + 8.3% small burnet + 8.3% birdsfoot trefoil. The diets (60 g DM/day) were fed twice daily. The periods were 10 d long with 6 d of adaptation and 4 d of sampling. Data were analyzed using a mixed model including the fixed effect of treatment and the random effects of period and fermenter.

Objective 3. Nine 30x40 m (0.12 ha) islands were established in a 22-ha grass-dominated pasture (Meadow brome; *Bromus inermis*), with locations selected for higher probabilities of seedling success and a spatial arrangement that optimizes livestock distribution. The limiting resource for plant establishment in semi-arid regions is water availability (Zhang et al. 2020). Thus, areas within the pasture with a higher density of vegetation represented locales where moisture was greater. To identify these locations, temporal sequence of satellite imagery was analyzed utilizing the European Space Agency's Sentinel-2 platform to generate yearly maps of vegetation density via the normalized difference vegetation index (NDVI). Cloud-free Sentinel-2 images spanning the current and preceding 5 years for July and August were identified and NDVI values extracted for each pixel. Median July-August NDVI for each year was calculated for each pixel in the pasture and all pixels were reduced to the mean and standard deviation. These metrics were used to locate pixels within a pasture whose greenness consistently deviated in a positive direction (higher than average greenness) from average pasture greenness. Spatial groupings of these consistently greener pixels served as candidate locations for island establishment, with potential better access to water and nutrients. After spatial selection, islands were seeded with strips (8x30 m each) of: 1-Alfalfa (*Medicago sativa*, containing saponins), 2-Birdsfoot trefoil (*Lotus corniculatus*, containing condensed tannins-CT), 3-Sainfoin (*Onobrychis viciifolia*, containing a different array of CT, 4-Small burnet (*Sanguisorba minor*, containing hydrolizable tannins), and 5-Forage kochia (*Bassia prostrata*, containing phenolic compounds). The percentage establishment of the five-forage species was monitored using the frequency grid method (Vogel and Masters 2001).

Extension personnel is working with a group of livestock producers across the state of Utah to establish a series of demonstration plots using the same approach described above. Locations that represented some of the varied range types throughout the state were selected, as well as those sites with the greatest potential benefit from the intervention proposed, such as those dominated by crested wheatgrass. The team is taking measurements using the frequency grid method (Vogel and Masters 2001) to determine how sites establish and persist under the typical grazing regime of the different operations and speak with producers to understand what they perceive as the primary costs and benefits of the proposed landscape interventions.

Objective 4. During the first year of the project, we sought input from Utah ranchers who are currently grazing livestock by distributing a short online video about the project through team networks, relevant listservs, and social media groups, and to a sample purchased from a private vendor and subsequently asked the ranchers to fill out a brief online survey. Utilizing insights from the survey, we then conducted structured in-depth interviews with 14 Utah ranchers in 2023.

Results

Objective 1. The introduced species sainfoin, small burnet and alfalfa were able to establish in relatively dense stands at every location, and the native species showy goldeneye, Rocky Mountain penstemon, Utah sweetvetch, and prairie coneflower as well as falcata alfalfa all averaged more than 5 plants m^{-1} at some locations. Of the species that performed well at multiple locations, sainfoin accumulates condensed tannins (CT) while small burnet and Utah sweetvetch accumulate both CT and hydrolizable tannins (HT) and are of particular interest because of the synergies between the two types of tannins in improving ruminant health and reducing environmental impacts.

Table 1. Plant species ranked by number of locations with at least 1 plant m^2, and within location, by plant count. Values are final 2023 plant counts.

Genus species	Common name	#Locations	Plants m^{-2}
Onobrychis viciifolia Scop.	Sainfoin	4	36
Medicago sativa L.	Alfalfa, 'Ladak'	4	12
Sanguisorba minor Scop.	Small burnet	4	12
Lotus corniculatus L.	Birdsfoot trefoil	4	3
Heliomeris multiflora Nutt.	Showy goldeneye	3	11
Medicago sativa L. ssp. falcata (L.) Arcang.	Alfalfa, falcata	3	7
Penstemon strictus Benth.	Rocky Mtn. penstemon	2	13
Hedysarum boreale Nutt.	Utah sweetvetch	2	9
Astragalus cicer L.	Cicer milkvetch	2	4
Agropyron cristatum L. Gaertn.	Crested wheatgrass	2	4
Helianthus maximiliani Schrad.	Maximillian sunflower	2	3
Penstemon palmeri A. Gray	Palmer's penstemon	2	2
Ratibida columnifera (Nutt.) Wooton & Standl.	Prairie coneflower	1	8
Securigera varia L. Lassen	Crownvetch	1	4
Dalea purpurea Vent	Purple prairie clover	1	2
Linum lewisii Pursh	Lewis flax	1	1
Balsamorhiza sagittata (Pursh) Nutt.	Arrowleaf balsamroot	1	1

Objective 2. Fiber digestibility was affected by the treatments ($P < 0.01$). The NDF digestibility of Treatment 1 (75% crested wheatgrass and 25% alfalfa) was the highest followed by Treatment 2 (75% crested wheatgrass and 25% sainfoin) and 5 (75% crested wheatgrass, 8.3% sainfoin, 8.3% small burnet, and 8.3% birdsfoot trefoil), while Treatments 3 (75% crested wheatgrass and 25% small burnet) and 4 (75% crested wheatgrass and 12.5 sainfoin, and 12.5% small burnet) had the lowest NDF digestibility values. Among the short-chain fatty acid analyzed, acetate was the only one affected by treatments ($P = 0.04$). The highest acetate concentration was observed for Treatment 1, which was followed by Treatment 2 and 5. Treatments 3and 4had the lowest acetate concentration. The ammonia nitrogen produced from treatment 1 and 2 had greater values, followed by treatment 4 and 5, treatment 3 did not differ compared to treatment 4 and 5, but when compared to treatments 1 and 2, it had the lowest value. No treatment effects were observed for protozoa cell count and pH. Similarly, no treatment effect was observed for microbial growth.

Objective 3.

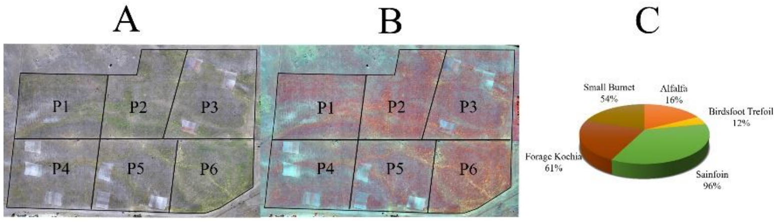

Figure 1. **A.** Natural color orthoimage generated from imagery collected on August 14, 2023, using a DJI Mavic 2 Pro unmanned aerial system (UAS). The 22-ha grass (Meadow brome; *Bromus inermis*)-dominated pasture in northern Utah (111º 48' 6" W, 41º 53' 22" N) shows the nine "islands" of 30x40 m (0.12 ha) each, distributed in three different fenced paddocks (P3, P4 and P5). Islands were seeded with strips (8x30 m each) of alfalfa, birdsfoot trefoil, sainfoin, small burnet, and forage kochia. Differences in color across the pasture represent variations in grass cover and species. **B.** Color infrared orthoimage generated from imagery collected by the same UAS filtered to the near infra-red of the same pasture taken on August 15, 2023. Differences in color across the pasture represent variations in grass cover and species. **C.** Overall percentage of frequency of forages in the islands shown in A and B.

Objective 4. The survey data indicates the participants are excited about the project, for gaining economic benefits, and in hopes of improved land management. Beyond themselves and the rangeland, they are also hopeful the project yields an outcome that will be beneficial and shared with the larger community in Utah such as increased environmental stewardship and enhancing plants and biodiversity. The ranchers who participated in the survey in Utah also stated several perceived potential challenges, largely centred around managing the smart foodscapes (SFS) within their existing ranching system, cost and time involved in comparison with future benefits, and external factors such as drought and weather change. Improved rangeland and optimistic perceptions about SFS are among the motivators for the ranchers for trying SFS in their operation in the future. Participants noted they still needed more information before trying SFS in their operation, particularly about the economics of making such transitions. Five key themes emerged, highlighting concerns about the time and resource intensity of SFS, management within existing operations, resistance to change, the need for more information, and the applicability of SFS to diverse landscapes. Economic considerations, water scarcity, and the reluctance to adopt new practices are key hurdles. These nuanced perspectives contribute valuable depth to the challenges identified in the survey, providing a comprehensive view of the complexities involved in the adoption of SFS in Utah's ranching community.

Discussion [Conclusions/Implications]

This project is filling the gap in knowledge about optimal synergistic/associative benefits for cattle and for the environment when animals graze a diversity of forage species with bioactive compounds. This research is devising diverse rangeland-based grazing systems aimed at optimizing ruminant production and health while reducing environmental impacts and enhancing biodiversity. This effort requires extensive analysis and synthesis of knowledge on the adaptability of plant species in the seeded islands, nutritional interactions among plant species, as well as a clear understanding of barriers to adoption. In turn, this new understanding is being communicated to producers and the public through demonstration plots and grazing schools. In summary, the transdisciplinary team assembled for this project is blending these variables into research, extension, and education programs to solve challenges to the sustainability of western rangelands. This project is improving natural resources quality through functional approaches that enhance livestock production and ecosystem diversity, while reducing the environmental footprint of beef production systems.

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