Creating phytochemically diverse foodscapes through landscape interventions

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ABSTRACT: Landscape interventions can lead to the establishment of resource patches or "islands" with a diversity of bioactive-containing forages (e.g., legumes, herbs, shrubs) in monotonous rangelands or pasturelands, viewed as a "sea" of low-diversity vegetation devoid of functional biochemicals. Strategies aimed at enhancing the diversity of plant communities promote heterogeneity in chemical, structural and functional landscape traits that offer options to foragers, and thus allow for balanced diets that improve nutrition and maintain or restore health. Such heterogeneity promotes a broad array of ecosystem services that significantly improve landscape resilience to environmental disturbances.

Keywords: plant secondary compounds, food Selection, grazing, biodiversity.

Introduction

In many parts of the world, rangelands and pasturelands are typically dominated by a low diversity of monotonous grass species that peak briefly in nutritional quality in spring and early summer, with declines in late summer through winter (Ganskopp and Bohnert, 2001). A low-quality nutritional environment decreases livestock performance and increases greenhouse gas emissions (Lee et al., 2017; Cole et al., 2020) with very low to nil provision of medicinal and therapeutic inputs of plant chemicals to the grazer (Wooding et al., 2021). Importantly, reliance on low-quality forage grasses harms maternal nutrition and triggers epigenetic effects *in utero* that negatively impact fetal development and subsequent lifetime productivity of the offspring (Broadhead et al., 2019). Costly supplementation programs (e.g., hays, grains, urea, molasses), are in general implemented to prevent these deficiencies, but with very low to nil provision of bioactive plant secondary compounds and thus the lack of meaningful medicinal/prophylactic inputs to the animal is not resolved even after supplementation. Supplementation programs often amount to 35-40% of total variable production costs (Adams et al., 1996). Unfortunately, climate change and its negative impact on forage availability and nutritional quality will only add to the need for nutritional supplementation (Dumont et al., 2015; Augustine et al., 2018).

A reversal of these trends in dietary quality, diversity and phytochemical richness requires landscape interventions that aim at enhancing chemical and taxonomic diversity in the landscape. Legumes and forbs usually have greater protein and non-fiber carbohydrate content than grasses (Hall et al., 1999; Phelan et al., 2015). This contributes to enhanced herbivore nutrition and feed conversion efficiencies, thus reducing enteric methane emissions to the atmosphere (Cole et al., 2020), with potential to promote shifts in macronutrient intake. More importantly, many of legumes, forbs and shrubs contain bioactives with medicinal, prophylactic and prebiotic activities that enhance animal health. In turn, phytochemical richness will enhance the likelihood of prophylactic and self-medicative behaviors through an increment in the rate of encounter of such chemicals in the feeding environment, allowing the animal the opportunity to build a diverse diet with the presence of bioactives. Even very small inputs of nutrients and functional biochemicals from forages can deliver improvements in animal health (Beck and Gregorini, 2020; Beck, 2020). Thus, it is possible to restructure landscapes through the strategic distribution of relatively small patches of legume- and forb-rich “islands” that can synergistically complement the forage resource already available to herbivores.

Resource islands can be viewed as nutrition centers and pharmacies where legumes, forbs and shrubs are strategically established in the landscape as clusters, offering animals choices and opportunities for prophylactic and self-medicative behaviors. Once these behaviors are learned by mothers and peers, social transmission of self-medication will enhance learning efficiency, creating cultures within the herd that ingest a diverse diet that prevents and treats disease.

It is possible to devise scenarios where the monotony of a “sea of grass” is broken by the establishment of islands that provide a diversity of plant species with prophylactic chemicals for daily consumption, and other island patches with plant species that contain greater content of bioactives (i.e., and potentially less palatable plants like shrubs) that allow for therapeutic self-medication. Ruminants have spatial memory (Howery et al., 1999; Hewitson et al., 2005) and individual and social learning will facilitate the rate of encounter with these patches. In addition, grazing plans and the use of physical or virtual fences or herders may create managerial approaches that guide the ingestion of therapeutic and prophylactic doses of plant bioactives in grazing circuits across the landscape. This concept has been applied by French herders with the use of grazing circuits or rotations in rangelands to stimulate dietary diversity and enable sheep to select nutritious diets (Meuret and Provenza, 2015).

Beyond representing a significant source of nutrients and bioactives to herbivores, islands of plant diversity are expected to provide multiple ecosystem services, like cleaner air due to reductions in enteric methane emissions caused by dietary polyphenols (Mueller-Harvey et al., 2019). In addition, condensed tannins promote reductions in the route of N excretion to urine, favoring increments in fecal N, which is mainly in the organic form and has to be mineralized to ammonium before being susceptible to volatilization (Cai et al., 2017). Reductions in the proportion of N partitioned to urine are also beneficial for air and soils, as they constrain NH_3 volatilization from urine and NO_3^- leached to groundwater and waterways (Leip et al., 2015). Moreover, condensed tannins in legumes inhibit N nitrification processes in soils, which mitigates soil N loss in pasture systems (Clemensen et al., 2020). Finally, reductions in urinary N ameliorate the production of the potent greenhouse gas N_2O (Bao et al., 2018). Islands of diversity with their flowering plants and structural diversity can serve as refugia and corridors within monotonous landscapes by providing habitat (e.g., structural cover, insect populations), connectivity and resources for target plant and animal species (Fischer et al., 2014). Inputs of new forages also contribute to healthy soils through increments in biomass and litter and aid in erosion control through root development (Gyssels and Poesen, 2003). Thus, the approach suggested creates multi-functional working landscapes (McGranahan, 2014) that benefit herbivores and the environment, making rangelands and pasturelands more resilient to climate change.

Restoration “islands” or plant patches are being used as a novel strategy to rehabilitate degraded and monotonous habitats efficiently and effectively in neotropical forests and some grassland ecosystems (see examples in Shaw et al., 2020). A fundamental premise is that these islands become sources of propagules that disperse outward across the degraded landscape, facilitating recovery (Reis et al. 2010). Thus, the approach proposed for phytochemically diverse islands also represents a restoration tool for some habitats.

The challenge ahead entails devising foodscapes and chemoscapes that facilitate in herbivores the opportunity to select the types and combinations of phytochemicals that allow and facilitate efficient nutritional, prophylactic and therapeutic self-medicative behaviors, creating cultures within herds that foster these behaviors trans-generationally. Transdisciplinary collaborations between, agronomists, landscape architects, range scientists, nutritionists, behaviorists, land managers and ranchers could lead to integrated approaches. For instance, explore when, where, which species and combinations to use, devising grazing plans to enhance behavior by consequences and social learning in animals grazing different landscapes, thus creating more sustainable, resilient and biodiverse systems.

Landscape interventions to enhance phytochemical diversity in rangelands

An example on how to strategically deploy resource islands into the landscape and multidisciplinary collaboration is provided in Figure 1, where nine 30x40 m (0.12 ha) islands were established in a 22-ha grass-dominated pasture (Meadow brome; *Bromus inermis*). We located areas within the pasture for island establishment aiming at higher probabilities for seedling success and a spatial arrangement that optimizes livestock distribution. To locate such sites, we focused on the premise that the limiting resource for plant establishment in semi-arid regions is water availability (Muñoz-Rojas et al., 2016; Zhang et al., 2020). We assumed, therefore, areas within the pasture with a higher density or amount of vegetation represented areas where moisture was greater (Dang et al., 2020; Yang et al., 2023). To identify these locations and to determine that they consistently had a greater vegetation density every year, we analyzed a temporal sequence of satellite imagery utilizing the European Space Agency's Sentinel-2 platform to generate yearly maps of vegetation density via the normalized difference vegetation index (NDVI) (Rouse et al., 1973, Robinson et al., 2018). Cloud-free Sentinel-2 images spanning the current and preceding 5 years (6 years total) and only for the months of July and August were identified and NDVI values extracted for each pixel. The months of July and August were selected to avoid the variability of Spring weather and capture the pasture prior to grass senescence. 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 (SD). 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 measured in mid-summer. All pixels within the pasture and for each given year were compared to that year's mean and SD and only those pixels whose NDVI value were above 1 standard deviation from the mean were retained. All years were then superimposed and the frequency of pixel > 1SD was calculated resulting in a map of the number of years (0-6) that a given pixel recorded an NDVI that was 1SD greater than the mean of that year. A value of 6 identified pixels that consistently met the >1SD criteria, a value of 0 represented pixels that were never >1SD. The result identified micro topographic variations (very small gullies) within a seemingly flat pasture where water was more prevalent. 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 then seeded with strips (8x30 m each) of: 1-Alfalfa (*Medicago sativa*, containing saponins), 2-Birdsfoot trefoil (*Lotus corniculatus*, containing condensed tannins), 3-Sainfoin (*Onobrychis viciifolia*, containing a different array of condensed tannins, 4-Small burnet (*Sanguisorba minor*, containing hydrolizable tannins), and 5-Forage kochia (*Bassia prostrata*, containing phenolic compounds) (Figure

1). Beef cattle will be tested for the prophylactic benefits of grazing this combination of bioactive-containing forages as they are rotated among islands while they graze meadow brome as their basal diet. It is predicted that grazing diverse foodscapes will increase animal performance, reduce enteric methane emissions, and improve immunological and antioxidant status in cattle. A greater forage diversity may also lead to more carbon storage in soils and an improved habitat for birds and pollinators.

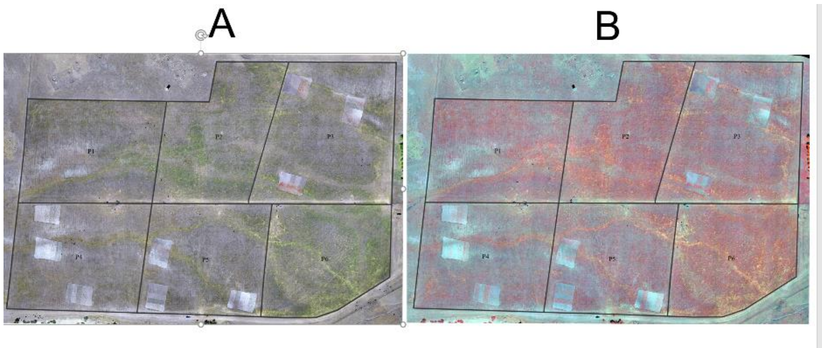

Figure 1. A. Natural color orthoimage generated from imagery collected on August 14, 2023, using a DJI Mavic 2 Pro unmanned aerial system (UAS). The 22-ha grass (Meadow brome; *Bromus inermis*)-dominated pasture in northern Utah (111º 48' 6" W, 41º 53' 22" N) shows the nine "islands" of 30x40 m (0.12 ha) each, distributed in three different fenced paddocks (P3, P4 and P5). Islands are seeded with strips (8x30 m each) of: 1-Alfalfa (*Medicago sativa*, containing saponins), 2-Birdsfoot trefoil (*Lotus corniculatus*, containing condensed tannins), 3-Sainfoin (*Onobrychis viciifolia*, containing condensed tannins, 4-Small burnet (*Sanguisorba minor*, containing hydrolizable tannins), and 5-Forage kochia (*Bassia prostrata*, containing phenolic compounds). 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.

Conclusions

Single forage species or grasses limit the ability of grazing or browsing herbivores to build a diet that maintains or improves animal nutrition and health. Strategic distribution of nutritionally-dense and phytochemically-rich forages in space and time could be integrated with knowledge about foraging principles to build new managerial dimensions in livestock production systems. In addition to the medicinal and nutritional inputs that maintain and restore health, landscape interventions that promote plant diversity will provide a broader array of services that significantly improve ecosystem sustainability and resilience to environmental disturbances.

References

Adams D.C., Clark R.T., Kloptenstein T.J., Volesky J.D., 1996. Matching the cow with forage resources. Rangelands 18, 57-62.

Augustine D.J., Blumenthal D.M., Springer T.L., LeCain D.R., Gunter S.A., Derner J.D., 2018. Elevated CO_2 induces substantial and persistent declines in forage quality irrespective of warming in mixed grass prairie. Ecological Applications 28, 721-735.

Bao, Y., Zhou, K., Zhao, G., 2018. Nitrous oxide emissions from the urine of beef cattle as regulated by dietary crude protein and gallic acid. Journal of Animal Science 96, 3699-3711.

Beck, M.R., 2020. Dietary phytochemical diversity to enhance health, welfare and production of grazing ruminants, while reducing environmental impact. PhD thesis, Lincoln University, New Zealand.

Beck, M.R., Gregorini, P. 2020., How dietary diversity enhances hedonic and eudaimonic well-being in grazing ruminants. Frontiers in Veterinary Science, 7:191.

Broadhead D., Mulliniks J.T., Funston R.N., 2019 Developmental programming in a beef production system. Veterinary Clinics: Food Animal Practice 35, 379-390.

Cai, Y., Chang, S.X., Cheng, Y., 2017. Greenhouse gas emissions from excreta patches of grazing animals and their mitigation strategies. Earth-Science Reviews 171, 44-57.

Clemensen, A.K., Villalba, J.J., Rottinghaus, G.E., Lee, S.T., Provenza, F.D., Reeve, J.R., 2020. Do plant secondary metabolite-containing forages influence soil processes in pasture systems? Agronomy Journal 112, 3744-3757.

Cole N.A., Meyer B.E., Parker D.B., Neel J., Turner K.E., Northup B.K., Jennings T., Jennings J.S., 2020. Effects of diet quality on energy metabolism and methane production by beef steers fed a warm-season grass-based hay diet. Applied Animal Science 36, 652-667.

Dang, Z.Q., Huang, Z., Tian, F.P., Liu, Y., López-Vicente, M., Wu, G. L., 2020. Five-year soil moisture response of typical cultivated grasslands in a semiarid area: Implications for vegetation restoration. Land Degradation & Development 31, 1078-1085.

Dumont B., Andueza D., Niderkorn V., Lüscher A., Porqueddu C., Picon-Cochard C., 2015. A meta-analysis of climate change effects on forage quality in grasslands: Specificities of mountain and Mediterranean areas. Grass and Forage Science 70, 239-254.

Fischer J., Abson D.J, Butsic V., Chappell M.J., Ekroos J., Hanspach J., Kuemmerle T., Smith H.G., von Wehrden H., 2014. Land sparing versus land sharing: moving forward. Conservation Letters 7, 149-157.

Ganskopp, D., Bohnert, D., 2001. Nutritional dynamics of 7 northern Great Basin grasses. Journal of Range Management 54, 640-647.

Gyssels, G., Poesen, J., 2003. The importance of plant root characteristics in controlling concentrated flow erosion rates. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group 28, 371-384.

Hall, M.B., Hoover, W.H., Jennings, J.P., Webster, T.K., 1999. A method for partitioning neutral detergent-soluble carbohydrates. Journal of the Science of Food and Agriculture 79, 2079-2086.

Hewitson, L., Dumont, B., Gordon, I.J., 2005. Response of foraging sheep to variability in the spatial distribution of resources. Animal Behaviour 69, 1069-1076.

Howery, L.D., Bailey, D.W., Laca, E.A., 1999. Impact of spatial memory on habitat use. Grazing Behavior of Livestock and Wildlife 70, 91-100.

Lee M.A., Davis A.P., Chagunda M.G., Manning P., 2017. Forage quality declines with rising temperatures, with implications for livestock production and methane emissions. Biogeosciences 14, 1403-1417.

McGranahan D.A., 2014. Ecologies of scale: Multifunctionality connects conservation and agriculture across fields, farms, and landscapes. Land 3, 739-769.

Meuret, M., Provenza, F.D., 2015. When art and science meet: integrating knowledge of French herders with science of foraging behavior. Rangeland Ecology & Management 68, 1-17.

Mueller-Harvey, I., Bee, G., Dohme-Meier, F., Hoste, H., Karonen, M., Kölliker, R., Lüscher, A., Niderkorn, V., Pellikaan, W.F., Salminen, J.P., and Skøt, L., 2019. Benefits of condensed tannins in forage legumes fed to ruminants: Importance of structure, concentration, and diet composition. Crop Science 59, 861-885.

Muñoz-Rojas, M., Erickson, T.E., Martini, D.C., Dixon, K.W., Merritt, D.J., 2016. Climate and soil factors influencing seedling recruitment of plant species used for dryland restoration. Soil 2, 287-298.

Phelan, P., Moloney, A.P., McGeough, E.J., Humphreys, J., Bertilsson, J., O'Riordan, E.G., O'Kiely, P., 2015. Forage legumes for grazing and conserving in ruminant production systems. Critical Reviews in Plant Sciences 34, 281-326.

Reis A., Bechara F.C., Tres D.R., 2010. Nucleation in tropical ecological restoration. Scientia Agricola 67, 244–250.

Robinson N.P., Allred B.W., Smith W.K., Jones M.O., Moreno A., Erickson T.A., Naugle D.E., Running S.W., 2018. Terrestrial primary production for the conterminous United States derived from Landsat 30 m and MODIS 250 m. Remote Sensing in Ecology and Conservation 4, 264-280.

Rouse J.W., Haas R.H., Schell J.A., Deering D.W., 1973. Monitoring vegetation systems in the Great Plains with ERTS, Third ERTS Symposium, NASA SP-351 I, 309-317.

Shaw, J.A., Roche, L.M., Gornish, E.S., 2020. The use of spatially patterned methods for vegetation restoration and management across systems. Restoration Ecology 28, 766-775.

Wooding, S.P., Ramirez, V.A., Behrens, M., 2021. Bitter taste receptors: Genes, evolution and health. Evolution, Medicine, and Public Health 9, 431-447.

Yang Q, Huang W, Jozwik C, Lin Y, Glasman M, Caohuy H, Srivastava M, Esposito D, Gillette W, Hartley J, Pollard HB (2005) Cardiac glycosides inhibit TNF-alpha/NF-kappaB signaling by blocking recruitment of TNF receptor-associated death domain to the TNF receptor. Proceedings of the National Academy of Science 102:9631–9636.

Yang, X., Zhang, Z., Guan, Q., Zhang, E., Sun, Y., Yan, Y., & Du, Q., 2023. Coupling mechanism between vegetation and multi-depth soil moisture in arid–semiarid area: Shift of dominant role from vegetation to soil moisture. Forest Ecology and Management. 546, 121323.

Zhang, Q., Wei, W., Chen, L., Yang, L., Chen, H. Y., Luo, Y., 2020. Soil water availability drives changes in community traits along a hydrothermal gradient in loess plateau grasslands. Rangeland Ecology & Management 73, 276-284.