Soil-Based Vegetation Productivity Models for Disturbed Lands along the Northern and Central, Western Great Plains, USA

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***Abstract*—Planners, designers, soil scientists, foresters, agronomists, government agencies, and concerned citizens are interested in reliable and predictable methods to reconstruct and manage disturbed and native soil resources for optimum plant productivity. In our study, we developed predictive models to assess neo-soil reconstruction for study areas in Montana, Wyoming, and Colorado. We developed models to predict plant growth based upon soil characteristics for agronomic crops, rangeland, and woody plants. Our results indicated that potentially three to four dimensions of plant growth could produce predictive models, $p<0.0001$, explaining 71% to 88% of the variance. Regression models employed the main-effect variables, squared terms, and first order interaction terms for: soil reaction, percent organic matter, electrical conductivity, percent slope, bulk density, hydraulic conductivity, available water holding capacity, topographic position, percent rock fragments, and percent clay, with each regressor containing a p-value less than 0.05.**

***Index Terms*—sustainable agriculture, environmental design, landscape architecture, disturbed land, landscape planning, soil conservation**

I. Introduction

Agricultural soil resources are an important resource for national economic development and environmental health. These soils are primarily composed of solids (50%), gases (25%), and liquids (25%) and are quite different than soils necessary for roads and buildings (95% soils and 5% fluids), rarely suitable for both uses [1]. To predict the vegetation productivity of soils, investigators have searched for equations to quickly and quantitatively assess the suitability of these soils for vegetation growth for orchards, forests, farmlands, rangeland, turf, gardens, wetlands, and ornamental plantings [2]-[4]. Across the globe, a large proportion of soils are no longer native but rather managed soils affiliated with anthropocence activities. For these soils (neo-sols or anthrosols), it is helpful to be able to predict their productivity potential. Planners, designers, soil scientists, foresters, agronomists, governmental agencies, and concerned citizens are interested in these approaches.

Some of the earliest prediction equations originated in surface mining applications derived in the late 1980s and early 1990s in Minnesota and North Dakota [5]-[8]. The studies discovered that most plants in the study area covaried is soil preference, including plants such as sunflowers (*Helianthus annuus* L.), soy beans (*Glycine max* (L.) Merr.), wheat (*Triticum aestivum* L.), pasture land, and many woody plants, with a preference for mesic soil conditions. It was also discovered that sugar beets (*Beta vulgaris* L.) preferred a soil with more clay and somewhat more wet, tolerating soils with more salinity [9]. In 1993, a similar study in Florida identified a group of plants preferring mesic conditions and another set preferring hydric conditions [10]. In North Dakota, a larger region was examined (a three-county area), with the generation of a mesic preference equation for vegetation in a coal mining area, including an illustration concerning the application of the equations to reconstruct disturbed lands [11]-[13]. These studies became part of a book on surface mine reclamation, *Environmental Design for Reclaiming Surface Mines*, earning an American Society of Landscape Architecture award for research [14]. Two French investigators explored this approach in Michigan, also discovering a mesic soil preference equation [15]. For a time, interest in developing such equations was minimal, as federal funds to conduct soil productivity research was reduced, and a simpler and more practical approach was employed placing the best soils on top four feet (1.22 m) of the soil profile. A second wave of interest began when Chinese

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investigators were interested in the methodology, with the publication of productivity models in Georgia and Wisconsin for vegetation seeking mesic conditions [16], [17]. Besides producing these equations, the relationships of these approaches to American reclamation laws were examined [18], [19]. One mesic preference equation was applied to an urban area in Grand Rapids, Michigan and explored with Environmental Protection Agency (EPA) water use calculations [20]. In addition, other investigators have attempted to predict soil productivity employing various methods on mined lands across forests of the Eastern United States or in hot dry valleys in China [21], [22]. These studies comprise the essential literature associated with this approach with an overview of the work of the key investigator of this line of research, Dr. Burley, *From Eye to Heart: Exterior Spaces Explored and Explained* [23]. The efforts of this group represent only initial investigations in this approach. There are many more locations to explore.

One potentially unexplored region is the western portion of the Great Plains, including Montana, Wyoming, and Colorado. The aim of this study in this article is to describe the relationship between plant productivity and soil properties, to predict plant growth, developing soil-based productivity equations in the study site of Montana, Wyoming, and Colorado, USA.

II. Study Area and Methdology

A. Study Area

One county in each of the three states located in the general study area were selected for model development: Prairie County, Montana; Campbell Country, Wyoming; and Washington Country, Colorado (Fig. 1) [24]-[28]. Each of the counties are situated in the northwestern portion of the American Great Plains, a dry mid-continental steppe landscape with temperatures as low in winter as -30 degrees C., and in summer temperatures often exceeding 30 degrees C., with yearly rainfall often below 30 inches (75 cm), and sometimes less than 90 frost free days in the summer [24]-[28]. The *Atlas of the Great Plains* provides additional information concerning the geography of the area [29].

Figure 1. A map illustrating the general locations of the three study areas in the investigation.

B. Statistical Analysis

Soil science investigators have established the ten essential main effects variables to select in predicting soil productivity: topographic position, % slope, % rock fragments, % clay, bulk density, hydraulic conductivity, available water holding capacity, soil reaction, electrical conductivity, and % organic matter. Data for these counties were collected by the former Soil Conservation, now the Natural Resource Conservation Service [24]-[28]. To collect the data per county, it often takes approximately 1 million American dollars to map the locations of the soils, measure the properties of the soil, and to grow various crops on the soil measuring vegetation productivity, taking often 10 years or more to complete. To develop independent variables, the soil parameters (such as electrical conductivity) are averaged with a weighted formula from the top of the soil profile downward, where the top foot contributes 40% of the total contribution, the second foot contributes 30%, the third foot contributes 20% and the fourth foot contributes 10%, as explained by Burley and Thomsen [4].

The dependent variables are derived from vegetation yields in each county. The vegetation for Prairie County examined includes: irrigated and non-irrigated spring and winter wheat (*Triticum aestivum* L.), irrigated and non-irrigated barley (*Hordeum vulgare* L.), irrigated and non-irrigated alfalfa (*Medicago sativa* L.), irrigated and non-irrigated hay, irrigated and non-irrigated corn for silage (*Zea mays* L.), non-irrigated sugar beets (*Beta vulgaris* L.), Nanking cherry (*Prunus tomentosa* Thunb.), western sand cherry (*Prunus pumila* var. *besseyi* (Bailey) Gleason), blue spruce (*Picea pungens* Engelm.), common chokecherry (*Prunus virginiana* L.), lilac (*Syringa vulgaris* L.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), Siberian crabapple (*Malus baccata* (L.) Borkh. 1803), Siberian peashrub (*Caragana arborescens* Lam.), green ash (*Fraxinus pennsylvanica* Marshall), ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), Russian olive (*Elaeagnus angustifolia* L.), Siberian elm (*Ulmus pumila* L.) (*Zea mays* L.), skunkbush sumac (*Rhus trilobata* Nutt.), Tatarian honeysuckle (*Lonicera tatarica* L.), and silver buffaloberry (*Shepheria argentea* Nutt.). The vegetation variables for past studies in North Dakota, Minnesota, Wisconsin, Michigan, Georgia, and Florida did not contain irrigated crops. Thus by employing the vegetation variables from Prairie County, there is an opportunity to examine the effects upon the potential differences between irrigated and non-irrigated soil for plant productivity.

For Campbell Country, Wyoming, the crops studied include: barley (*Avena sativa* L. (1753)), hay, oats (*Avena sativa* L. (1753)), pasture, alfalfa (*Medicago sativa* L.), winter wheat (*Triticum aestivum* L.), and rangeland. Like Campbell County, Washington County, Colorado, had a limited and less diverse group of vegetation to study, including: corn (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench), alfalfa hay (*Medicago sativa* L.), winter wheat (*Triticum aestivum* L.), sunflowers (*Helianthus annuus* L.), and rangeland.

These plant types are employed to derive and estimate of vegetation productivity. However, the term, “vegetation productivity”, is a somewhat relatively weakly developed construct/paradigm. In many respects, vegetation productivity has been operationally expressed by examining plant biomass such a through as vegetation yield, e.g. bushels per acre of harvested seed or feet of new apical terminal shoot growth per year. It represents a particular anthropocentric view concerning plant growth. The statistical approach examines covariance in vegetation productivity as supported by the results of others such as Burley, Thomsen, and Kenkel, and Burley and Bauer [8], [10]. This is an important statistical concept that may not be familiar to numerous investigators. Through Principal Component Analysis (PCA), a multivariate technique, it is possible to study how the measurements of seeming disparate variables (such a tons per acre or feet per year, and bushels per year can be examined collectively. If all vegetation types do not covary in productivity, then the researcher must develop an individually tailored plant productivity equation. It means that the soil must be tailored to each vegetation type. If plants do covary, a universal vegetation productivity equation may be potentially formed that is suitable for many types of plants. The PCA statistical method is quite useful and has been applied in other types of studies including social/cultural science studies [30]-[32]. PCA allows linear combination of productivity values to be established and computed (the dependent variable). In PCA, eigenvalues are generated (independent orthogonal dimensions). Usually eigenvalues greater than 1.0 are considered for potential equation development, although past studies have shown that only the first through the third eigenvalues produce equations that explain substantial variance (greater than 60%). Then the independent soil variables including main effects, squared terms, and first order interaction terms are employed in a regression study to determine the best statistically derived equation that explains the largest variance as well as identifies all significant proposed regressors in the equations with a p-value less than 0.05.

In summary the process to conduct the research consists of measuring the properties of soil profiles and growing crops on these profile for approximately 10 years. Then employing a 40/30/20/10 depth weighting formula for each soil variable on each soil (independent variables). Next, use PCA to derive weighted linear combinations of plant yields/growth (dependent variable) across the soil profiles. Main effects, squared terms, and first order interaction terms are regressed to predict plant growth. The best predictor equations are those that explain the most variance without being over-specific, containing only significant variables ($p \leq 0.05$).

III. Results

In a study of Prairie County, Montana, 58 soil profiles were used in the investigation. A PCA of the 25 crops employed to generate productivity linear combinations, produced 6 significant eigenvalues (Table I). The first eigenvalues explain 38.85% of the variance across all the 25 vegetation types. Table II presents the eigenvector coefficients for the first three eigenvalues (dimensions). Tables III and IV illustrate the results of the regression analysis for the first eigenvalue in Prairie County, Montana. The equation that can be derived from Table IV explains 84.6% of the variance, and has a Cp value of 9.34, meaning it is not over-specified.

TABLE I. Prairie County, Montana Eigenvalues for the 25 Vegetation Types

Eigenvalues of the Covariance Matrix			
Eigenvalue	Difference	Proportion	Cumulative
9.71327372	4.49821996	0.3885	0.3885
5.21505376	1.58017385	0.2086	0.5971
3.63487992	1.28902329	0.1454	0.7425
2.34585663	0.95196322	0.0938	0.8364
1.39389341	0.36395479	0.0558	0.8921
1.02993862	0.40366976	0.0412	0.9333

TABLE II. Prairie County, Montana Eigenvector Coefficients for the First Three Eigenvalue Dimensions

Crop	Prin1	Prin2	Prin3
Spring Wheat	0.064422	0.219826	0.330383
Winter Wheat	-.025357	0.120760	0.102779
Barley	0.071805	0.220859	0.337104
Alfalfa	0.033579	0.263256	0.369563
Corn Silage	0.006783	0.278807	0.358420
Sugar Beets	-.003861	0.280843	0.346551
Irrigated Spring Wheat	0.242255	-.041998	0.023027
Irrigated Winter Wheat	0.244305	-.034447	0.025489
Irrigated Barley	0.239727	-.034063	0.021387
Irrigated Alfalfa	-.031217	0.087798	-.007896
Irrigated Corn Silage	0.287480	-.118134	0.019318
Western Sand Cherry	0.254331	0.070182	0.049455
Blue Spruce	0.287480	-.118134	0.019318
Chokecherry	-.130921	0.128230	-.193723
Lilac	0.287480	-.118134	0.019318
Rocky Mountain Juniper	0.183533	0.301064	-.231702
Siberian Crabapple	0.287480	-.118134	0.019318
Siberian Peashrub	0.183533	0.301064	-.231702
Green Ash	0.287480	-.118134	0.019318
Ponderosa Pine	0.183533	0.301064	-.231702
Russian Olive	0.183533	0.301064	-.231702
Siberian Elm	0.183533	0.301064	-.231702
Skunkbush Sumac	-.210783	0.266844	-.130987
Tartarian Honeysuckle	0.274985	-.129127	0.026735
Silver Buffaloberry	-.168904	0.135501	-.227295

TABLE III. OVERALL MODEL RESULTS FOR PRAIRIE COUNTY, MONTANA FIRST EIGENVALUE (DIMENSIONS)

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	468.06965	66.86709	39.24	<.0001
Error	50	85.19581	1.70392		
Corrected Total	57	553.26546			

TABLE IV. BEST SELECTED MODEL FOR PRAIRIE COUNTY, MONTANA FIRST EIGENVALUE (DIMENSION) WHERE: AW= AVAILABLE WATERHOLDING CAPACITY; HC= HYDRAULIC CONDUCTIVITY; SA= SALINITY (RELATED TO ELECTRICAL CONDUCTIVITY); TP= TOPOGRAPHIC POSITION; SL = % SLOPE; 2= SQUARE COEFFICIENT. A COMBINATION OF TERMS INDICATES AN INTERACTION TERM

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-10.59480	2.62500	27.75711	16.29	0.0002
AW	85.58539	13.60812	67.39863	39.56	<.0001
HC	-0.83051	0.35551	9.29919	5.46	0.0235
SA	-0.80806	0.16503	40.84936	23.97	<.0001
TP2	-0.38554	0.07936	40.21678	23.60	<.0001
HC2	0.10760	0.02906	23.35774	13.71	0.0005
SLHC	-0.04481	0.01395	17.58560	10.32	0.0023
HCSA	0.24868	0.10307	9.91840	5.82	0.0195

In an examination of Campbell County, Wyoming, 25 soil profiles were used in the investigation. A PCA of the 7 crops employed to generate productivity linear combinations, produced 2 significant eigenvalues (Table V). The first eigenvalue explains 74.35% of the variance across all the 7 vegetation types. Table VI illustrates the eigenvector coefficients for the first two eigenvalues (dimensions). Tables VII and VIII illustrate the results of the regression analysis for the first eigenvalue for Campbell County, Wyoming. The equation is highly definitive, explaining 99.72% of the variance, with a Cp value of 75.2, meaning the equation is not over-specified.

TABLE V. CAMPBELL COUNTY, WYOMING EIGENVALUES FOR THE 7 VEGETATION TYPES

Eigenvalues of the Covariance Matrix			
Eigenvalue	Difference	Proportion	Cumulative
5.20418665	4.20403483	0.7435	0.7435
1.00015182	0.44704755	0.1429	0.8863

TABLE VI. CAMPBELL COUNTY, WYOMING EIGENVECTOR COEFFICIENTS FOR THE FIRST EIGENVALUE DIMENSIONS

Crop	Prin1	Prin2
Barley	0.064422	0.219826
Grassland Hay	-.025357	0.120760
Oats	0.071805	0.220859
Alfalfa	0.033579	0.263256
Pasture	0.006783	0.278807
Alfalfa	-.003861	0.280843
Winter Wheat	0.242255	-.041998
Rangeland	0.055261	0.989782

TABLE VII. OVERALL MODEL RESULTS FOR CAMPBELL COUNTY, WYOMING FIRST EIGENVALUE (DIMENSIONS)

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	124.55220	6.55538	94.09	<.0001
Error	5	0.34837	0.06967		
Corrected Total	24	125.90057			

In a study of Washington County, Colorado, 38 soil profiles were used in the statistical analysis. A PCA of the 6 crops employed to generate productivity linear combinations, produced 2 significant eigenvalues (Table IX). The first eigenvalue explains 49.87% of the variance across all the 6 vegetation types. Table X illustrates the eigenvector coefficients for the first two eigenvalues (dimensions). Tables XI and XII present the results of the regression analysis for the first eigenvalue for Washington County, Colorado. The equation that can be derived from Table XII explains 88.9% of the variance, and has a Cp value of 64.24, meaning the equation is not over-specified.

TABLE VIII. BEST SELECTED MODEL FOR CAMPBELL COUNTY, WYOMING FIRST EIGENVALUE (DIMENSION) WHERE: TP= TOPOGRAPHIC POSITION; SL=% SLOPE; FR= % ROCK FRAGMENTS; CL= % CLAY; BD= BULK DENSITY; HC= HYDRAULIC CONDUCTIVITY; AW= AVAILABLE WATERHOLDING CAPACITY; EC= HYDRAULIC CONDUCTIVITY; OM= % ORGANIC MATTER; 2= SQUARE COEFFICIENT). A COMBINATION OF TERMS INDICATES AN INTERACTION TERM

Var.	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Inter.	-497.38	94.664	1.9234	27.61	0.0033
TP	-33.55	2.8538	9.629	138.20	<.0001
SL	-5.2190	0.6384	4.657	66.84	0.0004
FR	-20.168	1.624	10.743	154.19	<.0001
CL	-0.8759	0.10774	4.6048	66.09	0.0005
BD	848.170	139.36	2.5807	37.04	0.0017
HC	-1.2174	0.1234	6.7774	97.27	0.0002
AW	-153.06	18.129	4.9663	71.28	0.0004
EC	6.33020	0.45249	13.6367	195.7	<.0001
OM	35.0653	2.4381	14.4122	206.8	<.0001
SL2	-0.5088	0.04799	7.8304	112.4	0.0001
BD2	-311.92	51.125	2.5935	37.22	0.0017
AW2	4.27175	0.4844	5.4184	77.77	0.0003
PH2	-0.3610	0.03999	5.6856	81.60	0.0003
EC2	-0.5723	0.04267	12.5319	179.9	<.0001
OM2	-12.139	0.9854	10.573	151.7	<.0001
TPSL	5.3953	0.5348	7.0896	101.8	0.0002
TPCL	0.34046	0.04803	3.5001	50.24	0.0009
TPHC	0.3962	0.0597	3.0685	44.04	0.0012
TPAW	27.802	4.3147	2.8928	41.52	0.0013

TABLE IX. CAMPBELL COUNTY, WYOMING EIGENVALUES FOR THE 7 VEGETATION TYPES

Eigenvalues of the Covariance Matrix			
Eigenvalue	Difference	Proportion	Cumulative
2.99210980	1.68206052	0.4987	0.4987
1.31004928	0.64266481	0.2183	0.7170

TABLE X. WASHINGTON COUNTY, COLORADO EIGENVECTOR COEFFICIENTS FOR THE FIRST EIGENVALUE DIMENSIONS

Crop	Prin1	Prin2
Corn	0.505316	0.148347
Sorghum	0.502049	-.044610
Alfalfa	0.413967	0.215451
Winter Wheat	0.515222	-.004033
Sunflowers	0.236036	-.617466
Rangeland	0.008192	0.740475

TABLE XI. OVERALL MODEL RESULTS FOR WASHINGTON COUNTY, COLORADO FIRST EIGENVALUE (DIMENSIONS)

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	207.80812	18.89165	19.65	<.0001
Error	27	25.95259	0.96121		
Corrected Total	38	233.76072			

TABLE XII. BEST SELECTED MODEL FOR WASHINGTON COUNTY, COLORADO FIRST EIGENVALUE (DIMENSION) WHERE: OM= % ORGANIC MATTER; CL= % CLAY; TP= TOPOGRAPHIC POSITION; AW= AVAILABLE WATERHOLDING; HC= HYDRAULIC CONDUCTIVITY; CAPACITY SL=% SLOPE; FR= % ROCK FRAGMENTS; BD= BULK DENSITY; 2= SQUARE COEFFICIENT). A COMBINATION OF TERMS INDICATES AN INTERACTION TERM

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-17.33206	3.67197	21.4150	22.28	<.0001
OM	14.28001	1.50046	87.0607	90.57	<.0001
CL2	0.04234	0.00367	128.086	133.26	<.0001
HC2	-0.23626	0.03986	33.7781	35.14	<.0001
TPAW	82.15494	8.46808	90.4720	94.12	<.0001
TPOM	-3.91966	0.43557	77.8406	80.98	<.0001
SLHC	-0.01496	0.00698	4.41617	4.59	0.0412
FRBD	0.34075	0.08655	14.9006	15.50	0.0005
FRHC	-0.03224	0.01551	4.15491	4.32	0.0472
CLBD	-0.60349	0.13547	19.0759	19.85	0.0001
CLHC	0.24816	0.03656	44.2767	46.06	<.0001
CLAW	-11.20945	1.18013	86.7219	90.22	<.0001

IV. RESULTS AND CONCLUSION

The results suggest that it is possible to construct vegetation soil productivity models to predict plant growth in the northern and western Great Plains. The study of irrigated/non-irrigated lands in Prairie County, Montana revealed that the vegetation did not have covarying preferences for soil characteristics, requiring additional scrutiny. Washington County, Colorado expressed a vegetation covariance in preference for soil. Although, both Campbell County and Washington County suggested that the second eigenvalue (dimension) was associated with a soil preference affiliated with rangeland. This rangeland expression could be explored in a study of these second dimensions.

The complexity of the equations derived by the regression analysis at times make simple interpretations difficult. While these types of equations have been produced over the last 30 years, deep, thoughtful explorations of these equations have been absent. The equations suggest interactions and relationships between the variables that have yet to be explored in soil science.

Across the three regression equations presented in the study, the ten soil variables were significant in varying amplitudes. In other words, the initial variables identified as important over 40 years ago are apparently reasonable predictors. However, these variables are for non-toxic soils. If the soils contain toxic properties, other variables may need to be entered in the equations building process.

There is difficulty in comparing the results across counties. Each county operates somewhat independently when conducting their soil survey, especially when considering which crops and woody plants the county wishes to include in their study. There is more consistency in the soil properties described, although counties described over 40 years ago, may often contain a limited set of variables. The process of describing soils in such great detail across the nation along with the cost has meant the activity has taken decades and is yet to be complete (not all counties have yet to be described).

A comparison of soil productivity equations is often challenging with only limited experimentation and covariance comparisons [33], [34]. To illustrate the disparity across the regions and the equations developed, one can examine the predicted soil productivity. For example, in Prairie County, Montana, there is a soil known the "Busby" soil series residing on hills, stream terraces, sedimentary plains, and alluvial fans composed of both alluvium and eolian material covering about 1% of the county [23], [25]. This soil profile is comprised of a very deep well drained coarse loam, a mixed borollic (a cold temperature mollisol (temperate grassland soil)) camborthids (a weakly developed middle mineral horizon). The soil is droughty, susceptible to blowing, easily eroded by water, and has some rock outcrops. The soil is used from rangeland and growing grains, irrigated corn or irrigated alfalfa, and irrigated sugar beets. The soil has few to slight limitations for many recreational and built environment applications due to its sandy and well drained character.

Productivity is expressed as a range usually from -10 (low) to about 10 (high) [8]. In Prairie County, the equation that can be derived from Table IV generates a score of approximately -1.785, a low to somewhat moderate score, while in Washington County, Colorado in a warmer climate approximately 600 miles to the south, the score is -5.868, with an increased 10 cm in evapotranspiration, making such a soil potentially drier and less productive without irrigation (34). Conversely, the score for Campbell County, which is only a couple hundred miles to the south of Prairie County, but up to 500 meters higher in elevation (meaning cooler), the score from the equation derived in Table XII is 10.07, a relatively high value.

In conclusion, it is possible to construct predictive equations to assess soil productivity on the Great Plains from extensive soil surveys at the county level. However, the interpretation and relationship of the equations to each other require further study.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dr. Burley was the principal investigator of the research and wrote the manuscript. Dr. Zhen Wu performed the statistical work on Prairie Country. Dr. Shuyue He and Dr. Xiaoying Li did the statistical work for Campbell and Washington counties. All authors in the team approved the manuscript.

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References

[1] J. B. Burley and D. Gray, "Soil ordination: Implications for post-mining disturbance land-uses," in *Proc. Meeting of American Society for Surface Mining and Reclamation*, Albuquerque, New Mexico, 2001, pp. 241-245.

[2] J. B. Burley, "Methodology for building soil based vegetation productivity equations: A statistical approach," in *Proc. Thirteenth Annual Meeting American Society for Surface Mining and Reclamation: Successes and Failures: Applying Research Results to Insure Reclamation Success*, 1996, pp. 789-798.

[3] J. B. Burley, "Vegetation productivity equations: An overview," in *Proc. the National Symposium on Prime Farmland Reclamation*, Urbana, Illinois, 1992, pp. 259-265.

[4] J. B. Burley and C. Thomsen, "Multivariate techniques to develop vegetation productivity models for neo-sols," in *Proc. Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation*, Lexington, KY, 1987, pp. 153-161.

[5] J. B. Burley, "A multi-county vegetation productivity equation for soil reclamation," in *Proc. Sudbury '95 - Mining and the Environment*, CANMET, Ottawa, 1995, pp. 1113-1122.

[6] J. B. Burley, "Vegetation productivity equation for reclaiming surface mines in Clay County, Minnesota," *International Journal of Surface Mining and Reclamation*, vol. 5, pp. 1-6, 1991.

[7] J. B. Burley and C. H. Thomsen, "Application of an agricultural soil productivity equation for reclaiming surface mines: Clay County, Minnesota," *International Journal of Surface Mining and Reclamation*, vol. 4, pp. 139-144, 1990.

[8] J. B. Burley, C. Thomsen, and N. Kenkel, "Development of an agricultural productivity model to reclaim surface mines in Clay County, Minnesota," *Environmental Management*, vol. 13, no. 5, pp. 631-638, 1989.

[9] J. B. Burley, "Sugarbeet productivity model for Clay County, Minnesota," *Journal of Sugar Beet Research*, vol. 27, no. 3 & 4, pp. 50-57, 1990.

[10] J. B. Burley and A. Bauer, "Neo-sol vegetation productivity equations for reclaiming disturbed landscapes: A central Florida example," in *Proc. the 10th Annual National Meeting of the American Society for Surface Mining and Reclamation*, Spokane, Washington, 1993, pp. 334-347.

[11] J. B. Burley, G. W. Fowler, K. Polakowski, and T. J. Brown, "Soil based vegetation productivity model for the North Dakota coal mining region," *International Journal of Surface Mining, Reclamation, and Environment*, vol. 15, no. 4, pp. 213-234, 2001.

[12] J. B. Burley, K. J. Polakowski, and G. Fowler, "Constructing vegetation productivity equations by employing undisturbed soils data: An Oliver County, North Dakota case study," in *Proc. Thirteenth Annual Meeting American Society for Surface Mining and Reclamation: Successes and Failures: Applying Research Results to Insure Reclamation Success*, 1996, pp. 393-401.

[13] J. B. Burley, "A spatial application of a vegetation productivity equation for neo-sol reconstruction," in *Proc. American Society for Surface Mining and Reclamation 16th Annual National Meeting in conjunction with Western Region Ash Group 2nd Annual Forum*, Scottsdale, Arizona, 1999, pp. 708-714.

[14] J. B. Burley, *Environmental Design for Reclaiming Surface Mines*, Lewiston, NY: Edwin Mellen Press, 2001.

[15] G. L. Cleac'h, M. Salles, and J. B. Burley, "Vegetation productivity model for Grand Traverse County, Michigan," in *Proc. Joint Conference, 21st National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force*, 2004, p. 34.

[16] Q. Chang, Y. Bai, J. B. Burley, and S. Partin, "Soil-based vegetation productivity model for mined lands in Chippewa County, Wisconsin," in *Proc. the 13th International Conference on Environment, Ecosystems and Development*, Kuala Lumpur, Malaysia, 2015, pp. 15-22.

[17] Y. Bai, Q. Chang, C. Guo, J. B. Burley, and S. Partin, "Neo-sol productivity models for disturbed lands in Wisconsin and Georgia, USA," *International Journal of Energy and Environment*, vol. 10, pp. 52-60, 2016.

[18] J. B. Burley, "Soil productivity laws and regulations: An American case study," in *Environmental Design for Reclaiming Surface Mines*, J. B. Burley, Ed., Lewiston, NY: Edwin Mellen Press, 2001, pp. 75-95.

[19] J. B. Burley, "Vegetation productivity equation compatibility with selected state environmental reclamation laws and regulations," in *Proc. International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage*, 1994, pp. 294-303.

[20] J. B. Burley, N. Li, J. Ying, H. Tian, and S. Troost, "Chapter 3: Metrics in master planning low impact development for Grand Rapids, Michigan," in *Sustainable Urbanization*, M. Egren, Ed., Rijeka, Croatia: Intech, 2013, pp. 61-86.

[21] J. A. Rodrique and J. A. Burger, "Forest soil productivity of mined land in the Midwestern and Eastern Coalfield regions," *Soil Science Society of America Journal*, vol. 68, pp. 833-844, 2004.

[22] X. W. Duan, X. Han, J. M. Hu, D. Feng, and L. Rong, "A novel model to assess soil productivity in the dry-hot valleys of China," *Journal of Mountain Science*, vol. 14, no. 4, 2017.

[23] J. B. Burley and T. Machemer, *From Eye to Heart: Exterior Spaces* Explored *and Explained*, 1st ed., San Diego, CA: Cognella Academic Publishing, 2016.

[24] A. N. Benson, M. F. Browne, J. M. Setera, and J. H. Smith, *Soil Survey of Prairie County Montana: Part 1*, United States Department of Agriculture, Natural Resources Conservation Service, 1996.

[25] A. N. Benson, M. F. Browne, J. M. Setera, and J. H. Smith, *Soil Survey of Prairie County Montana: Part 2*, United States Department of Agriculture, Natural Resources Conservation Service, 1996.

[26] C. Prink, *Soil Survey of Campbell County, Wyoming, Northern Part*, United States Department of Agriculture, Natural Resources Conservation Service, 2007.

[27] J. W. Westerman and C. Prink, *Soil Survey of Campbell County, Wyoming, Southern Part*, United States Department of Agriculture, Natural Resources Conservation Service, 2004.
[28] M. L. Peterson, J. A. Crabb, and R. J. Larsen, *Soil Survey of Washington County Colorado*, United States Department of Agriculture, Natural Resources Conservation Service, 1986.
[29] S. J. Lavin, J. C. Archer, F. M. Shelley, J. C. Hudson, and D. J. Wishart, *Atlas of the Great Plains*, Lincoln, NE: University of Nebraska Press, 2001.
[30] H. Xu, J. B. Burley, P. Crawford, Y. Wang, Z. Yue, and R. Schutzki, "An ordination of western and Chinese burial sites," *WSEAS Transactions on Environment and Development*, vol. 13, pp. 452-469, 2017.
[31] Y. Xu, J. B. Burley, P. Machemer, and A. Allen, "A dimensional comparison between classical Chinese gardens and modern Chinese gardens," *WSEAS Transactions on Environment and Development*, vol. 12, pp. 200-213, 2016.
[32] J. B. Burley and T. J. Brown, "Constructing interpretable environments from multidimensional data: GIS suitability overlays and principal component analysis," *Journal of Environmental Planning and Management*, vol. 38, no. 4, pp. 537-550, 1995.
[33] J. B. Burley, "Vegetation productivity equations for the North Dakota coal fields," Ph.D. dissertation, Landscape Architecture, University of Michigan, Ann Arbor, MI, USA, 1995.
[34] W. E. Sanford and D. L. Selnick, "Estimation of evapotranspiration across the conterminous United States using a regression with climate and land-cover data," *Journal of American Water Resources Association*, vol. 49, no. 1, pp. 217-230, 2013.

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