Neo-sol Productivity Models for Disturbed Lands in Wisconsin and Georgia, USA

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***Abstract*—** Planners, designers, scientists, government agencies, and concerned citizens are interested in reliable and predictable methods to reconstruct soil resources disturbed by surface mining. In our study, we developed a predictive model to assess neo-soil reconstruction for Chippewa County, Wisconsin, USA, an area being mined for silica sand in glass production. We were developing a model to predict plant growth based upon soil characteristics for corn (*Zea mays* L.), corn silage, oats (*Avena sativa* L. (1753)), alfalfa hay (*Medicago sativa* L.), red clover hay (*Trifolium pretense* L.), Kentucky bluegrass (*Poa pratensis* L.), soybeans (*Glycine max* (L.)Merr.), northern white cedar (*Thuja occidentalis* L.), lilac (*Syringa vulgaris* L.), American cranberry bush (*Viburnum trilobum* Marshall), amur maple (*Acer ginnala* Maxim.), gray dogwood (*Cornus recemosa* Lam.), Siberian peashrub (*Caragana arborescens* Lam.), white spruce (*Picea glauca* (Moench) Voss), eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), red pine (*Pinus resinosa* Sol. Ex Aiton), jack pine (*Pinus banksianna* Lamb.), nannyberry viburnum (*Vibrunum lentago* L.), and white ash (*Fraxinus americana* L.), all plants and crops commonly grown in the county. Our results indicated that potentially four dimensions of plant growth could produce a predictive model, explaining 87.24% of the variance; however, only the first dimensions produced a viable model explaining 41.08% of the variance. This first dimension predicted plant growth across all plant types, containing all positive eigenvector coefficients. The regression model employed the variables: soil reaction, percent organic matter, percent slope, hydraulic conductivity, topographic position, percent rock fragments, and percent clay, each with a p-value less than 0.05. The equation explained 77.55% of the variance in the first dimension and was significant at a value less than p<0.0001). This equation can be relied upon to predict vegetation plant growth correctly 9999 times in 10,000 attempts. Such equations reduce the need for costly reference areas and the need to grow vegetation on the reclaimed land to assess soil reconstruction which can take up to 10 years to determine.

We repeated a similar study for three agricultural counties in Georgia, USA: Bleckley, Dodge, and Telfair counties. Mining in this area is primarily comprised of local sand and gravel mines. A prediction model was developed based upon plant growth for twelve vegetation types: corn (*Zea mays* L.), soybeans (*Glycine max* (L.)Merr.), wheat (*Triticum aestivum* L.), cotton (*Gossypium hirsutum* L.), tobacco (*Nicotiana tabacum* L.), peanuts (*Arachis hypogaea* L.), Bermuda grass (Cynodon dactylon (L.) Pers.), slash pine (*Pinus elliottii* Engelm.), longleaf pine (Pinus palustris Mill.), loblolly pine (*Pinus taeda*) L., sweetgum (*Liguidamabar styraciflua* L.) and tulip tree (*Liriodendron tulipifera* L.). An equation derived from the first dimension explained almost 80% of the variance with ten regressors plus an intercept as significant (p<0.05). For this first dimension, sweetgum did not covary with the other plant materials in the study.

***Keywords*—** design, disturbed land, environmental stewardship, landscape planning, landscape architecture, landscape engineering.

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I. Introduction

MINERAL resources are an important resource for national economic development. The search for these resources has led to the disturbance of forests, farmlands, pasture land and the soil resources residing upon the landscape. Several natural resources can be disturbed to obtain another natural resource. The proliferation of surface disturbed lands and the resulting environmental impacts have generated an increased interest in reclaiming these disturbed lands and restoring these environments into useful landscapes.

Portions of the research contained in this article were first presented in a conference held in Kuala Lumpur, Malaysia, April 2015 at the 13th International Conference on Environment, Ecosystems, and Development (EED) [1]. This article represents an extended version of this presentation with additional investigations concerning the topic.

According to the mine reclamation legislation in USA and China, ecological rehabilitation that can help to restore the land productivity is viewed as a very important way to reclaim mined lands [2, 3, 4]. The successful establishment of vegetation on reclaimed soils (neo-sols) is often an indicator of environmental quality reclamation and important for wildlife, recreation, housing, and other land-uses [4, 5, 6, 7, 8, 9, 10, 11, 12, 13].

In the post-mining reclamation process, the soil has been a key element that limits vegetation establishment. It has been established that the pH, fertility, density, and microbial activity are major attributes to post-mined soils. Sheoran found that when the pH value of soil is reduced below 5.5, plant growth is hindered due to phosphorus fixation, reduced population of N-fixing bacteria, and metal toxicities such as manganese or aluminum [14]. Reconstructed soils have vastly reduced hydraulic conductivity due to increased macropore space and bulk density and macronutrients such as N, P and K which are commonly found to be deficient in these types of soils [15, 16, 17]. So it is suggested that 3-4 feet of non-compacted media are needed to maintain available water contents adequate to support plant growth [14]. Moreover, microbial activity has been found to decrease with increased depth and compaction of soils [18, 19]. Without enough microorganisms, soils will be deficient of nutrients necessary to support vegetation growth [20]. As a result, reclamation specialists are concerned about the ability and degree to which reconstructed soils are able to support the plant growth.

There have been four general ecological models developed which predict post-mining soil productivity by vegetative growth of agricultural crops, rangeland plants and woody plants [21, 22]. One is a heuristic method known as the "reconstructing nature" approach. It is required that A, B and C soil horizons be stripped and stockpiled separately so that these horizons may be reapplied in the correct order during post-mining land reclamation [20]. Although supposedly to keep the original soil attributes, any mining activities still affect the soil. Dancer and Jansen as well as McSweeney *et al*. found that mixtures of B and C horizons showed greater vegetative growth compared to B horizon material alone [23, 24]. Stripping and reapplication of A horizon material is very important in reconstructing the prime farmland, but mandates of topsoil depths depend on the characteristics of the soil material and the crops to be planted [25]. So the characteristics of post-mined soils often are vastly different from the pre-mining ones. Restoring vegetation productivity levels based on attempted similar structure of pre-mining soil (not same soil conditions) is difficult. And the poor performance of this approach does not always provide a reliable source for predicting vegetative productivity.

The second model is a statistical model known as the "reference site" approach whereby the soil from an undisturbed site is required to be compared with a site near mined lands. Once no statistical difference between the site around the mined lands and the undisturbed lands have been achieved (meaning nearly or comparable vegetation yields in both areas), the land reclamation is deemed acceptable. It was found that post-mining soils have the potential to support forest vegetation based on the investigation of 25 reforestation sites in the Appalachian region of the eastern United States. As a result of the necessity for analyzing and comparing multiple differing sites over an extended period of time, Doll and Wollenhaupt describe this model is as an unreliable and expensive means of evaluating reclamation success [26]. Burley also notes that it does not give a quantified prediction of vegetative productivity potential and has the limitation of requiring extensive and costly field data collection [3].

The third model is an experience model known as the "sufficiency" approach. In this model the soil productivity is evaluated by the defined criteria and either accepted as sufficient or rejected based upon a series of expert tables and charts [20]. The tree heights were predicted as three point values representing conditions that are *good*, *fair* or *poor* for vegetative growth based upon soil data published by the Natural Resource Conservation Service [26, 27, 28]. Neill as well as Doll and Wollenhaupt later used most of the soil factors and plant measurements (such as height) for the regression analysis [27, 29]. In this model, however, the interactions of soil attributes are not considered, as well as the interactions of vegetation types [28]. Furthermore, vegetation variables and soil types are restricted to a limited number [4].

The final model is a statistical model known as the "regression analysis" approach. This model requires a data set derived from productivity of various species across all soil types averaged over a ten-year period to develop a reliable statistical productivity equation [3]. A substantial county-based soil attributes and vegetation productivity dataset has been compiled by the Natural Resources Conservation Service (NRCS) since the mid-1900s. This data has been utilized by multiple studies to alleviate the costs associated with vast data collection required for statistical regression analysis [3, 4, 20, 21, 30, 31). The first equation based on this method was explored to investigate vegetative productivity on a site in Minnesota, additional equations were then developed such as those in Clay County of Minnesota, Florida and North Dakota [4, 32, 33, 34]. This regression model is considered scientifically accurate [20].

The aim of this study is to examine the relationship between plant productivity and soil properties, based on whether the quantitative equation to be developed would predict plant growth and identify the significant soil attributes predicting the productivity of plants. The result presents a soil-based vegetation productivity model for surface mined lands of Chippewa County in Wisconsin (USA presented at a WSEAS conference in Kuala Lumpur, Malaysia) and extended new material for Bleckely, Dodge, and Telfair counties in Georgia [1].

II. Study Area and Methodology

A. Chippewa County, Wisconsin

Chippewa County is in west-central Wisconsin and is comprised of an ancient mountain range in the northeast—that has since eroded and disappeared—and a central plain in the southwest. The central plain is underlain with sandstone (silica sand – silicone dioxide – SiO_2) that is close to the surface of the earth that is suitable for use in oil and gas recovery operations. This silica sand is found in Cambrian (Jordan, Wonewoc, and Mt. Simon formations) and Ordovician (St. Peter Formation) rocks. Silica mining in Chippewa County has concentrated upon primarily Jordan sandstone and Wonewoc sandstone [35]. This landscape is experiencing land disturbance for the removal of silica sand for use in these oil and gas recovery operations. The surface soils are primarily composed of well-drained loams, silts, and sands [36]. Approximately 30 percent of the land remains in forested patches and in woodlots and plantations with a mixture of a cropland and a dairy land matrix across the hilly and rolling landscape, with dairy farming as the dominant agricultural enterprise [36]. The woodlots produce pulp for paper products, poles for fences, and timber.

B. Bleckley, Dodge, and Telfair Counties, Georgia

The three counties studied in Georgia area are primarily in the costal plain, relatively near the Atlantic Ocean, ranging from just above 30 meters to about 300 meters above the ocean [37]. The soils are composed of marine sediments. The three counties rely upon farming and woodlots for income, along with some light industry.

C. Statistical Analysis

The soil characteristics examined in this investigation include: topographic position, % slope, % rock fragments, % clay, bulk density, hydraulic conductivity, available water holding capacity, soil reaction, and % organic matter (Table 1). Data for this county have been collected by the former Soil Conservation Service [36, 37]. To construct an independent variable, the soil parameters (such as bulk density) are averaged with a weighted formula from the surface downward, where the top foot contributes 40% of the total value, the second foot contributes 30%, the third foot contributes 20% and the fourth foot contributes 10%, as implicated by Burley and Thomsen [29].

Sym	Factor	Unit of Measurement
FR	% Rock Fragments	Proportion by weight of particles >7.62 cm
CL	% Clay	Proportion by weight
BD	Bulk Density	Moist Bulk Density Grams/cm^3
HC	Hydraulic Conductivity	Inches/hour (1 inch = 2.54 cm)
PH	Soil Reaction	pH level
OM	% Organic Matter	Proportion by weight
AW	Available Water Holding Capacity	Inches/inches, cm/cm
TP	Topographic Position	Scale 1 to 5 Where 1 = Low (Bottomland) 2.5 = Mid-slope 5 = High (Ridge Lines)
SL	% Slope	(Rise/Run)*100

Table 1. Main effect independent variables and units of measurement from the U.S. Soil Conservation Service.

The dependent variables in Chippewa County are derived from vegetation yields. The vegetation examined includes: (*Zea mays* L.), corn silage, oats (*Avena sativa* L. (1753), alfalfa hay (*Medicago sativa* L.), red clover hay (*Trifolium pretense* L.), Kentucky bluegrass (*Poa pratensis* L.), soybeans (*Glycine max* (L.)Merr.), northern white cedar (*Thuja occidentalis* L.), lilac (*Syringa vulgaris* L.), American cranberry bush (*Viburnum trilobum* Marshall), amur maple (*Acer ginnala* Maxim.), gray dogwood (*Cornus recemosa* Lam.), Siberian peashrub (*Caragana arborescens* Lam.), white spruce (*Picea glauca* (Moench) Voss), eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), red pine (*Pinus resinosa* Sol. Ex Aiton), jack pine (*Pinus banksianna* Lamb.), nannyberry viburnum (*Vibrunum lentago* L.), and white ash (*Fraxinus americana* L.).

The dependent variables for the three counties in Georgia are also derived from plant yields. The vegetation studied for the three counties in Georgia include: corn (*Zea mays* L.), soybeans (*Glycine max* (L.)Merr.), wheat (*Triticum aestivum* L.), cotton (*Gossypium hirsutum* L.), tobacco (*Nicotiana tabacum* L.), peanuts (*Arachis hypogaea* L.), Bermuda grass (Cynodon dactylon (L.) Pers.), slash pine (*Pinus elliottii* Engelm.), longleaf pine (Pinus palustris Mill.), loblolly pine (*Pinus taeda*) L., sweetgum (*Liguidamabar styraciflua* L.) and tulip tree (*Liriodendron tulipifera* L.).

In both study locations, the plant types are employed to predict vegetation productivity. However, the term, “vegetation productivity”, is a relatively weakly developed construct. In many respects vegetation productivity has been operationally expressed as vegetation yield, e.g. bushels per acre of harvested seed or feet of new apical terminal shoot growth per year. It represents a certain anthropocentric perspective concerning plant growth. A plant physiologist may suggest that an abundance of seeds per acre does not necessarily mean that a vegetation type is internally healthy and an ecological conditional constructs for vegetation productivity. Nevertheless, existing measures of vegetation yield and new plant growth are assumed as reasonable indicators of productivity in this article, and the major study focus lies in the relationships between existing productivity measures and soil parameters. The method examines covariance in vegetation productivity as supported by the findings of others such as Burley and Thomsen, and Burley and Bauer [31, 34]. This is an important issue. If all vegetation types do not covary in productivity, then the investigator must develop a large number of individually tailored vegetation productivity equations and the reclamation specialist may reclaim a landscape suitable for one crop but not for another, thereby excluding future production options for the farmer. If plants do covary, a universal vegetation productivity equation may be possible for the study site. The procedures for this statistical method are described in detail by several authors [29, 38, 39]. Once the linear combination of productivity values has been established and computed (the dependent variable), then the independent variables including main effects, squared terms, and first order interaction terms are regressed to find the equation that explains the largest variance as well as identifies all significant proposed regressors. Main effect regressors, squared terms, and first order interaction terms comprise the independent variables.

III. RESULTS

A. Chippewa County, Wisconsin

The first four eigenvalues were found to be potentially suitable for constructing a *vegetation productivity* equation (Figure 1 and Table 2). The first eigenvalue contained an “all vegetation” eigenvector where each of the dependent variables had positive coefficients (Table 3) and contained approximately 41 percent of the variance, although red clover hay contained a weak positive value as an eigenvector coefficient. The second eigenvalue was predominantly a red clover hay, northern white cedar, red maple, nannyberry viburnum, and white ash eigenvector and possessed 30 percent of the variance. The third eigenvalue represented red clover hay, American cranberry bush, red pine, white pine and nannyberry viburnum with strong positive eigenvector coefficients. The third eigenvalue contained almost 10 percent of the variance. The fourth eigenvalue was a red clover hay, soybean, Siberian pea shrub, and nannyberry viburnum dominated variables, expressing over 6 percent of the variance.

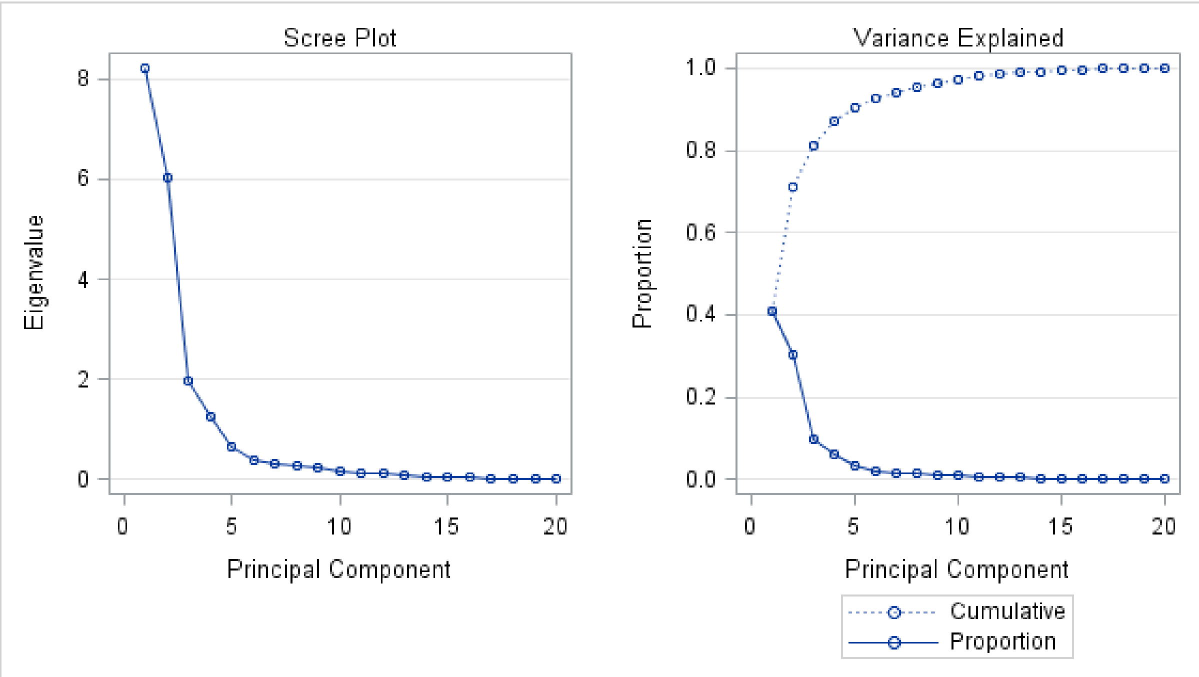

Figure 1. Principal component analysis eigenvalues for Chippewa County, Wisconsin.

Table 2. The first four principal component eigenvalues of the covariance matrix for Chippewa County, Wisconsin.

Principal Component	Eigenvalue	Difference	Proportion	Cumulative
PC1	8.21695143	2.18464775	0.4108	0.4108
PC2	6.03230367	4.07910207	0.3016	0.7125
PC3	1.95320161	0.70795730	0.0977	0.8101
PC4	1.24524430	0.57946824	0.0623	0.8724

Table 3. Eigenvalues for Chippewa County, Wisconsin.

	PC1	PC2	PC3	PC4
Corn	0.318902	0.039567	-.182856	0.202773
Corn silage	0.314024	0.038024	-.204029	0.215192
Oat	0.312032	0.055332	-.128419	0.189263
Alfalfa hay	0.238873	-.167054	-.343210	-.139657
Red clover hay	0.039849	0.297970	0.286752	0.397815
Kentucky bluegrass	0.259982	0.110449	-.278627	0.146321
Soybean	0.254792	0.073772	-.094920	0.289860
Northern white cedar	0.152437	0.281283	-.199512	-.140987
Lilac	0.313590	-.066306	0.196818	-.123397
American cranberry bush	0.238138	-.019002	0.445114	-.046757
Amur maple	0.206151	-.264098	-.109440	-.058187
Gray dogwood	0.234787	-.242320	-.003719	-.287729
Siberian Peashrub	0.116215	-.301648	0.113141	0.269697
White spruce	0.128658	0.321160	0.017535	-.331215
Eastern white pine	0.306372	-.071458	0.196250	-.081788
Rep maple	0.129096	0.350855	0.038891	-.235718

	PC1	PC2	PC3	PC4
Red pine	0.266541	-.082561	0.316504	-.238407
Jack pine	0.089419	-.322388	0.307509	0.105366
Nannyberry viburnum	0.047567	0.323648	0.278601	0.309848
White ash	0.115631	0.330770	0.087359	-.247918

Table 4. Best model found for the Stepwise Maximum R-squared Improvement for Principal Component 1, R-Square=0.7755, C (p)= 45.2000, Pr<.0001, Chippewa Counties.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-34.28235	4.29147	131.48112	63.82	<.0001
PH	14.58722	1.91859	119.10137	57.81	<.0001
OM	-4.82003	0.69414	99.34312	48.22	<.0001
SL2	-0.00350	0.00104	23.09439	11.21	0.0011
HC2	-0.05921	0.01823	21.73264	10.55	0.0015
PH2	-1.43219	0.20285	102.70370	49.85	<.0001
OM2	0.00684	0.00121	66.44916	32.25	<.0001
TPOM	0.13369	0.05758	11.10535	5.39	0.0221
FROM	-0.06490	0.01150	65.56963	31.83	<.0001
CLHC	-0.07706	0.01566	49.88431	24.21	<.0001
CLPH	0.03219	0.00882	27.45429	13.33	0.0004
HCPH	0.15241	0.05744	14.50787	7.04	0.0091
HCOM	0.11088	0.02459	41.88888	20.33	<.0001
PHOM	0.57254	0.10909	56.74852	27.54	<.0001

$$PLANT=-34.282+(14.587*PH)-(4.820*OM)-(0.004*SL*SL)-(0.060*HC*HC)-(1.432*PH*PH) +(0.007*OM*OM)+(0.134*TP*OM)-(0.064*FR*OM)-(0.078*CL*HC)+(0.032*HC*PH) +(0.111*HC*OM)+(0.573*PH*OM) \quad (1)$$

Table 5. The first four principal component eigenvalues of the covariance matrix for Bleckley, Dodge, and Telfair counties, Georgia.

Principal Component	Eigenvalue	Difference	Proportion	Cumulative
PC1	5.81806124	3.70101101	0.4475	0.4475
PC2	2.11705023	0.63253201	0.1629	0.6104
PC3	1.48451821	0.41053494	0.1142	0.7246
PC4	1.07398327	0.44439684	0.0826	0.8072

Table 6. Eigenvalues for Bleckley, Dodge, and Telfair counties, Georgia.

	PC1	PC2	PC3	PC4
Corn	0.389438	0.105036	0.017584	-.064550
Soybean	0.348573	0.131835	-.038227	-.109504
Wheat	0.327918	0.172740	-.114985	-.201263
Cotton	0.227541	0.373955	-.208808	0.181372
Tobacco	0.255438	0.111276	-.102825	0.378435
Peanut	0.319184	-.227009	0.095034	-.337632
Bermuda Grass	0.376884	0.053334	-.052953	-.046792
Slash Pine cedar	0.193740	-.437774	0.430393	0.080282
Longleaf Pine	0.216512	-.521046	0.085997	0.219430

	PC1	PC2	PC3	PC4
Sweetgum	-.088794	0.456834	0.434150	0.188830
Tulip Tree	0.001796	0.231120	0.608152	-.478560

PLANT=-6.642-(0.0065*CL2)-(0.0244*HC2) -(0.386*TP*FR)+(0.384*TP*PH)-(0.050*SL*FR) (2)
+(0.043*FR*CL* +(0.119*FR*HC)+(0.270*FR*OM)+(0.050*CL*PH)-(0.050CL*OM)

Table 7. Best model found for the Stepwise Maximum R-squared Improvement for Principal Component 1, R-Square=0.7992, C (p)= 149.72, Pr<.0001 for Bleckley, Dodge, and Telfair counties Georgia.

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-6.64202	1.23193	32.89326	29.07	<.0001
CL2	-0.00649	0.00160	18.52978	16.38	0.0003
HC2	-0.02436	0.01021	6.43816	5.69	0.0225
TPFR	-0.38574	0.09677	17.98026	15.89	0.0003
TPPH	0.38351	0.05935	47.24869	41.76	<.0001
SLFR	-0.05035	0.01023	27.43126	24.24	<.0001
FRCL	0.04342	0.00965	22.90187	20.24	<.0001
FRHC	0.11800	0.03374	13.84310	12.23	0.0013
FROM	0.27011	0.09335	9.47350	8.37	0.0064
CLPH	0.04989	0.01902	7.78339	6.88	0.0127
CLOM	-0.05027	0.01561	11.73255	10.37	0.0027

Only the first eigenvector produced a suitable equation (an equation with an r-squared over 50%). The results of the regression analysis are presented in Table 4. The equation predicted 77.55 percent of the variance for the first eigenvector, and contained 13 regressors and the intercept as significant ($p<0.05$). The plant production equation based on the soil properties is expressed in Equation 1.

B. Bleckely, Dodge, and Telfair Counties, Georgia

Similar to Chippewa County Wisconsin, the first four eigenvalues were found to be potentially suitable for constructing a *vegetation productivity* equation (Table 5). In addition, the first eigenvalue for the Georgia three county area did not contain an "all vegetation" eigenvector where each of the dependent variables had positive coefficients (Table 6) and contained approximately 44.75 percent of the variance. Sweetgum did not covary with the other vegetation. The second eigenvalue was predominantly a sweetgum and cotton dimension explaining over 16% of the variance. The third and fourth dimensions represent various combinations of vegetation aggregations. In our study we focused upon the first dimension.

The first dimension for the Georgia data produced an equation with an r-squared value of almost 80% and ten regressors plus an intercept as significant ($p<0.05$). The plant production equation based on the soil properties is expressed in Equation 2 as derived from Table 7.

IV. Discussion and Conclusion

The results suggest that it is possible to construct an "all vegetation" model to predict plant growth in both Chippewa County, Wisconsin and within the study area in Georgia relative to the composition of the soil. However, the Wisconsin model does not explain most of the variance in the complete data set, with about 60 percent remaining unexplained. Attempts to construct equations with the remaining 60 percent of the variance were unsuccessful. All vegetation equations developed for Michigan, North Dakota and Minnesota explained great proportions of the overall variance within the data set.

In the Wisconsin study area, red clover hay did not strongly covary with the other dependent variables in the study. The plant is a cool season short-lived perennial legume and not native to Wisconsin, although it has naturalized in the area. The plant is used for forage and hay. Investigators may wish to consider construction of a red clover specific equation such as the plant specific equation for sugarbeets (*Beta vulgaris* L.) developed by Burley [40].

For Wisconsin, bulk density and available water holding capacity were not present in the final equation (Equation 1). In other studies, such as in North Dakota (soils with lower bulk densities were often preferred as well as those soils with higher water holding capacity [22]. Two environmental conditions may account for the insignificance of these variables. First, in a cool temperate climate with adequate rainfall, retaining and holding moisture may not be an issue for vegetation. Second, with the predominance of loose, well-drained soils containing relatively little clay that remain un-compacted, the impact of densely compacted soils inhibiting plant growth may not be persistent in the subject county.

The equation does suggest several general properties for the county that influence plant growth. The first is the importance of raising the soil reaction in the soil. The county does have locations with low soil reaction and the equation suggests that managing and rebuilding soils with a higher soil reaction will improve plant growth. The equation also suggests that as the soil reaction increases, the vegetation will improve with an increase in organic matter. In addition, the equation suggests that as topographic position and hydraulic conductivity increase, soils with additional organic matter will be more productive. However, the squared term for soil reaction indicated that there is a maximum benefit to creating soils with higher soil reaction and, if the soil reaction is too high, the productivity begins to trend downward. The complexity of the equation suggests that with the number of various interaction terms, the overall composition of the soil is important to consider, thus managing any one variable can be difficult. Burley provides insight into how to develop a management plan and assess the landscape when applying these types of equations in disturbed environments [41].

The Georgia study area included the examination of sweetgum's soil preferences compared to eleven other plant types. Sweetgum did not appear to covary with the other vegetation and was strongly represented in the second dimension. Hightshoe notes that sweetgum is tolerant of floods and may have a slightly different environmental preference then the other eleven plants [42]. For example the tuplip tree (part of the group of eleven plants) is highly intolerant of flooding conditions [42]. Burley and Bauer had also discovered a cluster of plants when employing this methodology, with a similar preference for conditions more wet than a typical mesic environment [34]. Dimension three suggested that tulip tree may have a unique preference in the group of plants studied. Dimension four suggests that tobacco may have some unique requirements too. However, attempts to derived equations for the second, third, and fourth dimensions yielded weak equations with little explanatory power.

The pine trees in the Georgia study did not yield a strong xeric dimension. In contrast Coor discovered a strong xeric preference in northern Michigan for the pines in his study area [20]. Instead the pines of Georgia favored a strong mesic affiliation.

The results of both studies revealed a set of mesic seeking plants, similar to other studies in North Dakota, Minnesota, Michigan, and Florida [21, 22, 32, 33, 34]. This mesic seeking preference has not been widely studied by investigators and has only been identified in the last 30 years with a slow response to understand the underlying reasons for this preference [32]. The preference is only a part of the ecological puzzle, as the vegetation reported in this and other investigations controls competition between plants and supplements the growing plants with adequate water and nutrient levels. Scholars such a J.T. Curtis provide a more clear picture of the relationships between plants under competition [43].

As with other equations, the set of final regressors were only mildly similar between the two study areas. This may indicate that the influence of the soil regressors influencing plant growth may fluctuate across the eastern United States. If the set of regressors were more uniform, a universal mesic preference equation for all of the study areas may be relatively simple to construct. However, at this stage, it appears that the geographical position of the study areas (longitude and latitude) may be important regressors in the effort to develop a universal equation to predict neo-sol contribution to plant growth.

Opportunities exist to develop equations in many more study areas across the United States. The Natural Resources Conservation Service (NRCS) has complied many 'county-wide' databases that have never been analyzed. Only the raw data has been published, comprising of basic soil parameters, descriptions, general suitability, and maps. These data sets remain dormant awaiting investigators to explore the predicative nature of the soil variables to various land-uses and plant growth. Burley and Gray describe an example where the numerical relationship between site development and vegetation growth can be studied and examined with NRCS data sets [44]. Their study was in North Dakota.

In conclusion, it is possible to construct a predictive equation to assess soil variables for reconstructing disturbed landscapes in Chippewa County, Wisconsin and for three counties in Georgia. However, the equations presented in this research article suggests that the current prediction explains less than 50 percent of the total variance. Additional effort may be necessary to develop more reliable predictions in reclaiming the landscape. Opportunities to develop similar equations exist in many regions of the United States. The long-term goal may become to develop potential universal equations for large regions of the United States. Nations may wish to consider developing similar studies and databases for their part of the world.

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