A MODEL FOR EVALUATING AND COMPARING SOIL AND SITE FACTORS AFFECTING PRODUCTIVITY OF DISTURBED AND UNDISTURBED SIMILAR AND DISSIMILAR SOILS[1]

H. Raymond Sinclair, Jr., Robert R. Dobos, Sharon W. Waltman, Karl W. Hipple, and Joseph V. Chiaretti[2]

Abstract. The National Commodity Crop Productivity Index (NCCPI) is a model that generates soil productivity indices and allows the evaluation of arrayed similar soils or different soils. The NCCPI user guide explains three major environmental factors (soil properties, landscape features, and climate factors) and many subfactors and their relationships to each other and soil productivity. A cropland tillage system or any mechanical manipulation of the soil that, for example makes hydraulic conductivity (Ksat) slower than medium usually results in a lower crop index than the original soil. Physical soil properties, e.g., bulk density, Ksat, rock fragments within the soil, and other physical soil properties are more difficult to change by farming practices to a more favorable soil condition than chemical soil properties such as pH. Reconstructed soils after surface mining for coal generally have higher soil bulk density, lower soil root zone available water capacity, and slower hydraulic conductivity. These conditions tend to limit crop root growth and lower crop yields as compared to the pre-mined soils. The NCCPI model is a tool that demonstrates that lowering any of the three crop growth factors of a reclaimed soil will result in a lower index. Individual sub-factors can be compared to determine the reason(s) for index being lower for a reconstructed soil than for the pre-mined soil. NCCPI can be used to decide about disposing of undesirable subsurface soil horizons for plant growth and substitution of more favorable soil parent material as subsurface soil rooting media. After surface mining, the reconstructed prime farmland soils should have a positive value for the "water-gathering surface" subrule described in the NCCPI.

Additional Key Words: 7CFR657, SMCRA law, 30CFR823, State Regulatory Authority (SRA), and Office of Surface Mining (OSM), Root Zone Available Water Capacity (RZAWC).

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[2]H. Raymond Sinclair, Jr. and Robert R. Dobos are Soil Scientists, NSSC-NRCS, Lincoln, NE 68508. Sharon W. Waltman is Soil Scientist - Spatial Data Specialist, USDA-NRCS, Morgantown, West Virginia 26505. Karl W. Hipple is National Leader, Soil Survey Interpretations and Joseph V. Chiaretti is Soil Scientist, USSA-NRCS, Lincoln, NE.

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Introduction

The National Commodity Crop Productivity Index (NCCPI) is a USDA Natural Resources Conservation Service (NRCS) model that calculates soil productivity indices and allows the evaluation of arrayed similar or dissimilar soils. The NCCPI soil indices are numbers ranging from 0 to 1 with 1 being most productive. The NCCPI User Guide explains three major environmental factors (soil properties, landscape features and climate data) and many sub-factors and their relationships to each other and soil productivity (Dobos et al., 2008(a). ftp://ftp-fc.sc.egov.usda.gov/NSSC/NCCPI/NCCPI_user_guide.pdf) . Also, the soil and site properties used in the calculation of the overall index can be examined individually to determine the relationship of each to soil productivity. For example, a medium saturated hydraulic conductivity (Ksat) typically is well suited for growing most commodity farm crops. A cropland tillage system or any mechanical manipulation of the soil that, for example, makes Ksat slower than medium usually results in a lower crop index than that of the undisturbed soil (Sinclair et al., 2008). Physical soil properties, such as bulk density, Ksat, and rock fragment content, are more difficult to change by farming practices to a more favorable condition than are chemical properties, such as soil reaction (pH). Soils reconstructed after surface mining for coal generally have higher bulk density, lower root zone available water capacity, and slower saturated hydraulic conductivity (Sinclair et al., 2004 and 2005) than pre-mined soils. The available water capacity, hereinafter Root Zone Available Water Capacity (RZAWC) is the volume of water that should be available to plants if the soil, inclusive of rock fragments, is at field capacity. Reductions in RZAWC are made in the water retention difference due to incomplete root ramification that is associated with certain soil features such as fragipans, high bulk density, and/or other chemical and physical soil properties. These soil features are indicative of root restrictions. The amount of available water to the expected maximum depth of root penetration, commonly either 40 or 60 inches, or a physical or chemical root limitation, whichever is shallower (Soil Survey Division Staff, 1993). Dunker and Jansen (1987) document the importance of water, irrigated and non-irrigated soils, for crop productivity. Sinclair and Dobos (2006) provided an idea about how RZAWC is used in the Land Capability Classification System for evaluating reconstructed soils after mining to meet the rules and regulations in the Surface Mining Control and Reclamation Act of 1977 (public law 95-87).

Less favorable conditions in reconstructed soils tend to limit crop root growth and reduce crop yields as compared to the pre-mined soils (Dunker et al., 1991) and (Barnhisel et al., 2000). Reconstruction criteria for prime farmland soils after surface mining for coal are set forth in federal rules and regulations (30CFR823, 2008). The present federal law requires that soils designated as prime farmland (7 CFR657, 2008) be reconstructed back to cropland with yields equal to or greater than the pre-mined soil. Smith (1983) discusses options for evaluation of prime farmland reclamation success using soil survey versus crop production as a measure of soil productivity. The NCCPI model is a tool that demonstrates that lowering any one of the crop growth index factors of a reconstructed soil typically will result in a lower overall index. Certain subrules in NCCPI such as the "water-gathering surface" subrule, have more of a significant importance than some other subrules for crop production (Schroeder, 1992) and (Stuff and Dale, 1973). The "water-gathering surface" subrule needs to be an integral part of the reclamation plan for reconstructed soils. Individual sub-factors in the model can be compared to determine the reason(s) that reduce(s) the NCCPI for a reconstructed soil as compared to the pre-mined soil. During the planning process for future coal mine projects and before project plans are approved, NCCPI or a similar model should be used to generate baseline information that allows comparing soil properties, landscape features, and climate factors of the reconstructed soils to pre-mined soils. If the calculated index values for a reconstructed soil are less favorable than those of the pre-mined soil, then corrective action is warranted. The mining company and the state regulatory authority can consult with the USDA-Natural Resources Conservation Service to determine if agronomic and/or engineering technologies exist to reconstruct the mined soil to the pre-mined productivity as explained by Olson (1992).

Materials and Methods

The ability to array soils according to their inherent productivity for commodity crops is useful. In order to achieve this goal, many crop production indices have been devised (Olson and Lang, 2000; Persinger and Vogt, 1995; Soil Survey Staff, 2000; Storie, 1978) using a variety of methods. These methods work well in the confines of the areas for which they were developed. The NCCPI model (Dobos et al., 2008a and USDA-NRCS Soil Survey Staff, 2008b) uses the soil survey database (USDA-NRCS Soil Survey Staff. 2008a) of the United States to array the inherent productivity of soils for the production of commodity crops grown in the U.S.

The NCCPI is a refinement of the Soil Rating for Plant Growth (SRPG) model using technologies not available when SRPG was developed (Soil Survey Staff, 2000).

NCCPI uses the National Soils Information System (NASIS) database system. This database contains data for nearly 3000 soil survey areas. The geographic extent includes the continental United States, Alaska, Hawaii, Puerto Rico, and the U.S. territories in the Pacific Basin and Caribbean Areas. A variety of physical, chemical, landscape, and climatic data is available for the soils contained in the map units for each soil survey area. This system is currently housed in an INFORMIX relational database system. Data can be readily retrieved and manipulated using the NASIS-based Calculation/Validation, Interpretation and Reporting (CVIR) scripting language (Soil Survey Staff, 2002).

The interpretations module of the soil survey database system uses fuzzy logic to allow soils to be considered in terms of their degree of membership in the set of soils that are suitable for a particular land use. A statement can be made such as: "A soil that has a given set of characteristics is a non-member, partial member, or a full member of the set of soils having high inherent productivity". The degree of truthfulness ranges from zero (absolutely false) to one (absolutely true). The actual linkage between a soil characteristic and the degree of membership in the set of productive soils is based on a graphed function that describes the fuzzy set. The shape of the relationship can be specified to reflect the effect of an independent variable on a dependent variable, whether it is linear, sigmoidal, bell-shaped, or any other shape based on empirical evidence (Dobos et al., 2008a).

One of the challenges in fuzzy systems modeling is determining the relationship between the variables being modeled (Cox, 1994). In NCCPI, this task was handled by assembling a test dataset of soil survey areas found in the non-irrigated corn, soybeans, wheat, and cotton growing regions of the U.S. and then querying specific soil property data and plotting the results against the crop yield. Next, a spline curve was fitted to the scatter plot and the shape of this curve used to construct the fuzzy sets for each soil property (SAS Institute Inc, 2002). In particular, we wished to observe where the yield maxima or minima occurred in relation to increased levels of the variables and the slope of the lines before and after the maxima or minima.

One advantage of the technique used in NCCPI is that all the data used to develop the model is available in one place, the NASIS system (USDA-NRCS Soil Survey Staff, 2008a). This ensures that the ratings do not vary due to bias. Every person examining a particular soil survey area produces the same results. Another perceived benefit is that the large amount of data available for analysis will tend to compensate for any local inaccuracies when constructing the fuzzy sets. NCCPI is an empirical model that does not directly address why soil properties have an effect on yield.

Discussion

Figure 1 singles out the counties and their soil survey identifiers that are referenced in the tables and figures (Soil Survey Staff, 2008c).

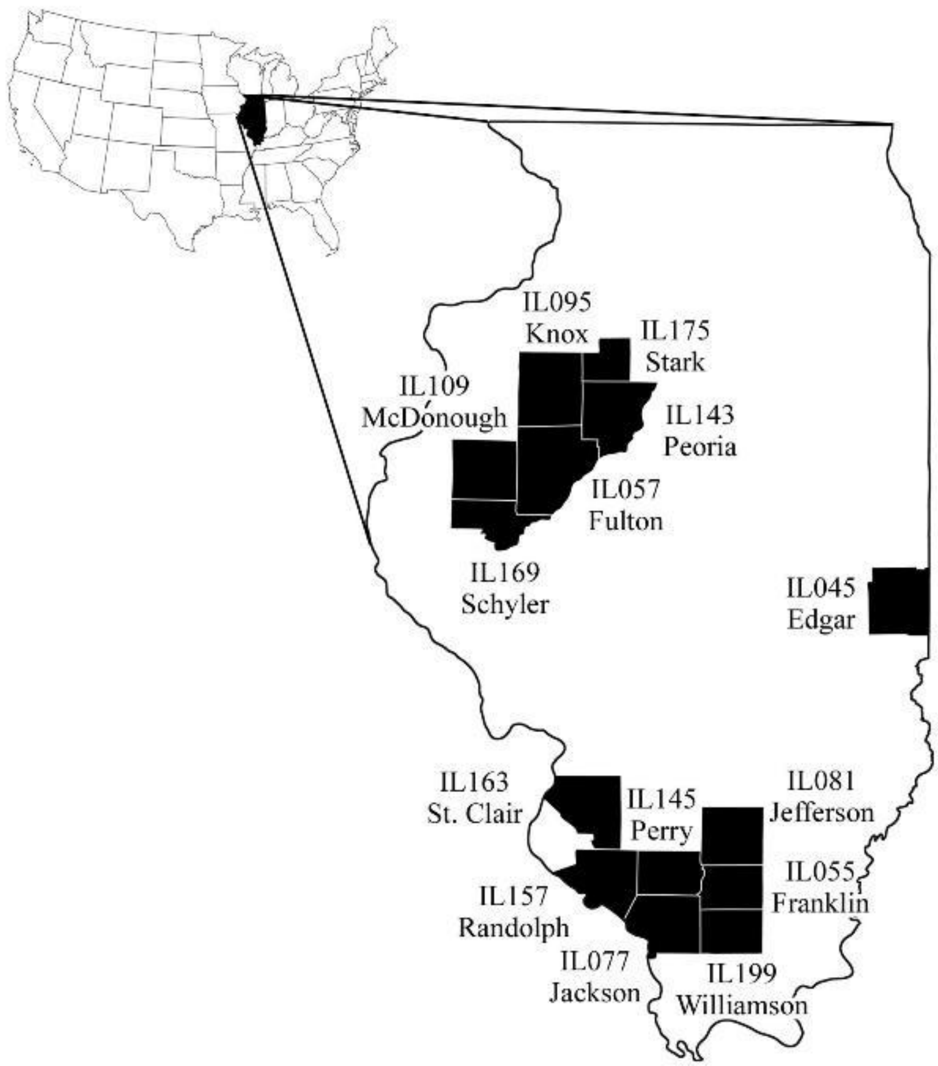

Figure1. Illinois County names (Edgar) and Their Soil Survey Identifiers (IL045) with Reconstructed Soil after Surface Mining for Coal.

Figures 2 and 3 give an idea about the spatial distribution of index classes of NCCPI for all soil map units in Fulton and Perry Counties, Illinois, respectively (Soil Survey Staff, 2008a-b). Overall Fulton County has higher indices than Perry County. Perry County does not have an extensive area of soils with indices of more than 0.80. For surface mining for coal in Perry County, this could be especially advantageous if a more desirable thick parent soil material can be mixed with or replace the existing less desirable subsurface soil horizons found in some of the current soils.

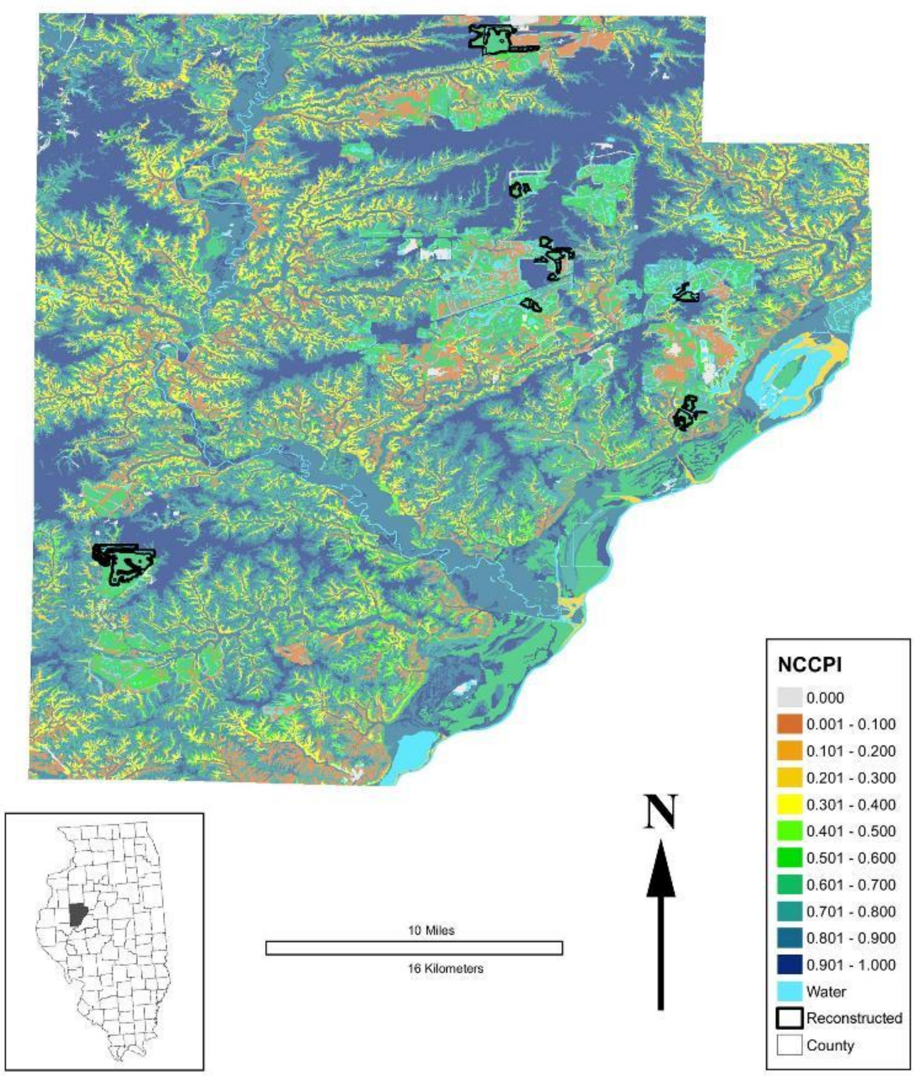

Figure 2. National Commodity Crop Productivity Indices (NCCPI) for All Soil Map Units in Fulton County, Illinois.

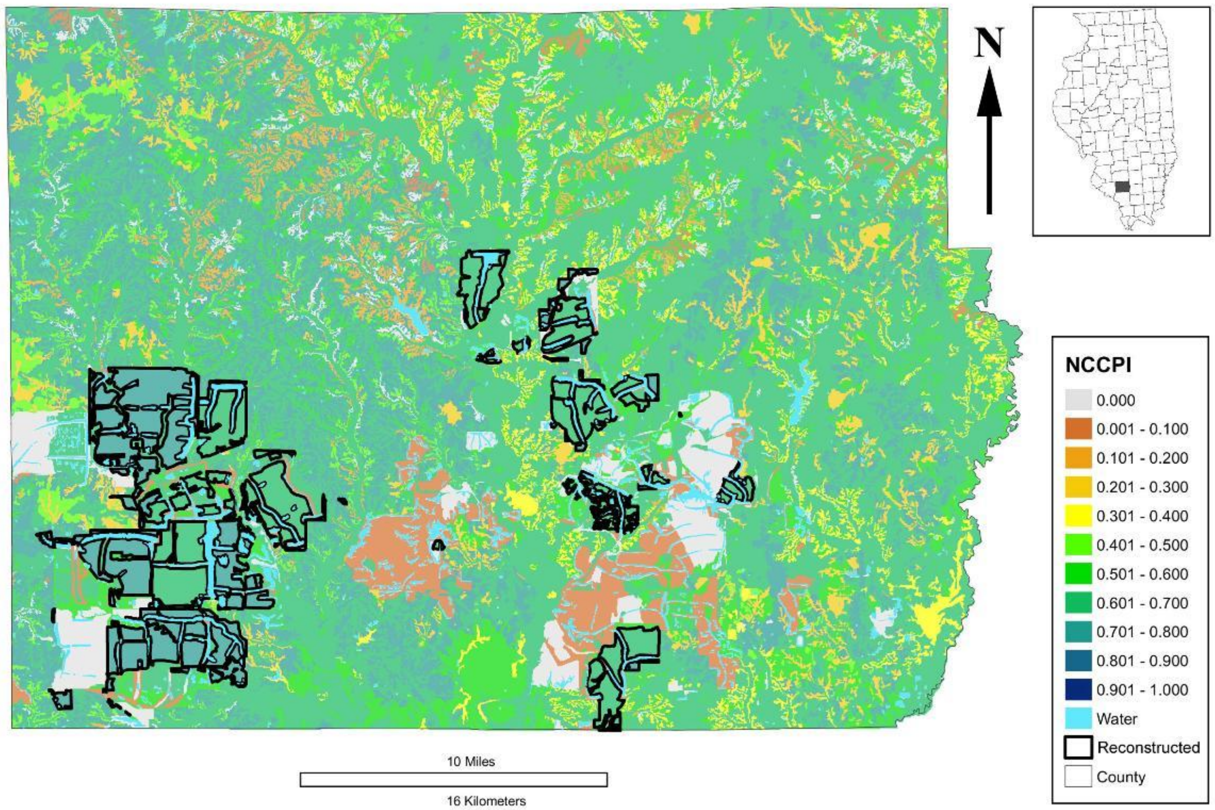

Figure 3. National Commodity Crop Productivity Indices (NCCPI) for All Soil Map Units in Perry County, Illinois.

Table 1(a-d) evaluates the important soil and site factors needed for growing corn and soybeans on level and gently sloping soils in Fulton and Perry counties (Dobos et al., 2006 and 2008(c)). Erosion subrule in NCCPI, a site factor, results in a lower index on eroded soils. Root Zone Available Water Capacity (RZAWC), a soil factor, influences NCCPI index more than most other physical soil properties. After surface mining, the reconstructed prime farmland soils should have a positive value for the "water-gathering surface" subrule, another site feature, as described in the NCCPI user guide by Dobos et al., 2008(a).

Table 1a. Soil map unit information, Land Capability Subclass, Farmland Designation and Soil Classification

State and Area Symbol	Soil Map Symbol	Soil Name	Surface Texture	Percent Slope	Land Capability Subclass (Non-irrigated)	Important Farmland	Soil Classification
IL145	14B	Ava	SIL	2-5	2e	Prime	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs
IL145	13A	Bluford	SIL	0-2	2w	Prime	Fine, smectitic, mesic Aeric Fragic Epiaqualfs
IL145	13B	Bluford	SIL	2-5	2e	Prime	Fine, smectitic, mesic Aeric Fragic Epiaqualfs
IL057	257A	Clarksdale	SIL	0-2	1---	Prime	Fine, smectitic, mesic Udollic Endoaqualfs
IL057	280B2	Fayette	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Typic Hapludalfs
IL145	582B	Homen	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs
IL145	3A	Hoyleton	SIL	0-2	2w	Prime	Fine, smectitic, mesic Aquollic Hapludalfs
IL145	3B	Hoyleton	SIL	2-5	2e	Prime	Fine, smectitic, mesic Aquollic Hapludalfs
IL057	43A	Ipava	SIL	0-2	1---	Prime	Fine, smectitic, mesic Aquic Argiudolls
IL057	17A	Keomah	SIL	0-2	2w	Prime	Fine, smectitic, mesic Aeric Endoaqualfs
IL057	17B	Keomah	SIL	2-5	2e	Prime	Fine, smectitic, mesic Aeric Endoaqualfs
IL057	86B	Osco	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Typic Argiudolls
IL057	872B	Rapatee	SICL	2-5	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Alfic Udarents
IL057	279B	Rozetta	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Typic Hapludalfs
IL057	279B	Rozetta	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Typic Hapludalfs
IL057	68A	Sable	SICL	0-2	2w	Prime	Fine-silty, mixed, superactive, mesic Typic Endoaquolls
IL057	823B	Schuline	SICL	1-7	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Typic Udorthents
IL145	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL145	164A	Stoy	SIL	0-2	2w	Prime	Fine-silty, mixed, superactive, mesic Fragiaquic Hapludalfs
IL145	164B	Stoy	SIL	2-5	2e	Prime	Fine-silty, mixed, superactive, mesic Fragiaquic Hapludalfs
IL145	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents

Table 1b. National Commodity Crop Productivity Index (NCCPI), positive/negative attributes, and chemical data[3] (Soil Survey Staff. 2008b)

Soil Map Symbol	NCCPI 1/ (Index)	Nega -tive Attri- butes	Frag- ments on Surface Subrule	Erosion Class Sub- rule	Rock Out- crop Sub- rule	No Surface Drainage Compo- nent	De- graded Surface Compo- nent	Posi- tive Attri- butes	Soil Fabric Sub- rule	Soil Chemical Properties Subrule	Root Zone CEC Su- rule	Root Zone pH Optimal Sub-rule	Root Zone OM Sub- rule
14B	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.74	0.98	0.82	0.92
13A	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.70	1.00	0.75	0.94
13B	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.70	1.00	0.75	0.94
257A	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.95	1.00	1.00	0.95
280B2	0.72	0.09	0.00	0.09	0.00	0.00	0.00	0.05	0.05	0.76	0.99	0.83	0.92
582B	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.82	1.00	0.88	0.93
3A	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.79	1.00	0.85	0.94
3B	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.79	1.00	0.85	0.94
43A	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.91	1.00	0.91	1.00
17A	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.80	1.00	0.87	0.92
17B	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.71	1.00	0.76	0.94
86B	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.87	1.00	0.88	0.99
872B	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.97	0.82	1.00
279B	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.80	1.00	0.85	0.94
279B	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.80	1.00	0.85	0.94
68A	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.93	1.00	0.93	1.00
823B	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.99	0.71	0.90
823B	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.98	0.72	0.93
164A	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.77	1.00	0.83	0.92
164B	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.78	1.00	0.83	0.94
824B	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	1.00	1.00	0.93

[3] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008. National Commodity Crop Productivity Index (NCCPI), Version 1.0

Table 1c. National Commodity Crop Productivity Index for Soil Adverse Chemical, Physical, and Landscape Properties[4] (Soil Survey Staff. 2008b)

Area Symbol	Map Symbol	Soil Adverse Chemical Properties	Root Zone EC Adverse Subrule	Root Zone Gypsum Adverse Subrule	Root Zone SAR Adverse Subrule	Soil Physical Properties Subrule	Ksat Minimum Subrule	Root Zone LEP Subrule
IL145	14B	1.00	1.00	1.00	1.00	0.61	0.76	1.00
IL145	13A	1.00	1.00	1.00	1.00	0.86	0.86	1.00
IL145	13B	1.00	1.00	1.00	1.00	0.86	0.86	1.00
IL057	257A	1.00	1.00	1.00	1.00	0.85	0.94	0.91
IL057	280B2	1.00	1.00	1.00	1.00	0.99	0.99	1.00
IL145	582B	1.00	1.00	1.00	1.00	0.91	0.93	1.00
IL145	3A	1.00	1.00	1.00	1.00	0.87	0.90	0.97
IL145	3B	1.00	1.00	1.00	1.00	0.87	0.90	0.97
IL057	43A	1.00	1.00	1.00	1.00	0.98	0.98	1.00
IL057	17A	1.00	1.00	1.00	1.00	0.90	0.94	0.96
IL057	17B	1.00	1.00	1.00	1.00	0.78	0.94	0.83
IL057	86B	1.00	1.00	1.00	1.00	0.98	0.98	1.00
IL057	872B	1.00	1.00	1.00	1.00	0.72	0.79	1.00
IL057	279B	1.00	1.00	1.00	1.00	0.98	0.98	1.00
IL057	279B	1.00	1.00	1.00	1.00	0.98	0.98	1.00
IL057	68A	1.00	1.00	1.00	1.00	0.98	0.98	1.00
IL057	823B	1.00	1.00	1.00	1.00	0.85	0.90	1.00
IL145	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL145	164A	1.00	1.00	1.00	1.00	0.87	0.87	1.00
IL145	164B	1.00	1.00	1.00	1.00	0.87	0.87	1.00
IL145	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95

[4] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008. National Commodity Crop Productivity Index (NCCPI), Version 1.0

Table 1c (continued)

Area Symbol	Map Symbol	Root Zone Bulk Density Subrule	Root Zone Rock Fragment Subrule	Root Zone Soil Depth Subrule	Soil Land-scape Subrule	Water Table Subrule	Effective Slope Subrule	Flooding Subrule	Ponding Subrule
IL145	14B	0.99	1.00	0.82	0.99	1.00	0.99	1.00	1.00
IL145	13A	1.00	1.00	1.00	0.96	0.97	1.00	1.00	1.00
IL145	13B	1.00	1.00	1.00	0.95	0.97	0.99	1.00	1.00
IL057	257A	1.00	1.00	1.00	0.96	0.97	1.00	1.00	1.00
IL057	280B2	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL145	582B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL145	3A	0.99	1.00	1.00	0.98	0.98	1.00	1.00	1.00
IL145	3B	0.99	1.00	1.00	0.97	0.98	0.99	1.00	1.00
IL057	43A	1.00	1.00	1.00	0.97	0.97	1.00	1.00	1.00
IL057	17A	1.00	1.00	1.00	0.96	0.97	1.00	1.00	1.00
IL057	17B	1.00	1.00	1.00	0.95	0.97	0.99	1.00	1.00
IL057	86B	0.99	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL057	872B	0.93	0.99	0.99	0.99	1.00	0.99	1.00	1.00
IL057	279B	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL057	279B	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL057	68A	1.00	1.00	1.00	0.94	0.95	1.00	1.00	0.99
IL057	823B	0.96	0.98	1.00	0.99	1.00	0.99	1.00	1.00
IL145	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL145	164A	1.00	1.00	1.00	0.98	0.98	1.00	1.00	1.00
IL145	164B	1.00	1.00	1.00	0.97	0.98	0.99	1.00	1.00
IL145	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00

Table 1d. National Commodity Crop Productivity Index for Climate and Water Subrules[5]

(Soil Survey Staff. 2008b)

Area Symbol	Map Symbol	Soil Climate Subrule	Frost-Free Days Subrule	Precipi-tation Subrule	Water Subrule	RZ AWC Subrule	Precipi-tation Recharge Subrule	Water Table Recharge Subrule	Water-Gathering Surface
IL145	14B	0.94	0.98	0.96	1.00	0.78	0.99	0.00	0.00
IL145	13A	0.94	0.98	0.96	1.00	0.83	0.99	0.00	0.00
IL145	13B	0.94	0.98	0.96	1.00	0.83	0.99	0.00	0.00
IL057	257A	0.99	1.00	0.99	1.00	0.96	0.99	0.00	0.00
IL057	280B2	1.00	1.00	1.00	1.00	0.92	0.83	0.00	0.00
IL145	582B	0.91	0.95	0.96	1.00	0.88	0.99	0.00	0.00
IL145	3A	0.94	0.98	0.96	1.00	0.84	0.99	0.00	0.00
IL145	3B	0.94	0.98	0.96	1.00	0.84	0.99	0.00	0.00
IL057	43A	1.00	1.00	1.00	1.00	0.94	0.96	0.00	0.30
IL057	17A	1.00	1.00	1.00	1.00	0.95	0.88	0.00	0.00
IL057	17B	1.00	1.00	1.00	1.00	0.94	0.88	0.00	0.00
IL057	86B	1.00	1.00	1.00	1.00	0.97	0.96	0.00	0.00
IL057	872B	0.98	1.00	0.98	1.00	0.77	0.96	0.00	0.00
IL057	279B	1.00	1.00	1.00	1.00	1.00	0.96	0.00	0.00
IL057	279B	1.00	1.00	1.00	1.00	1.00	0.96	0.00	0.00
IL057	68A	1.00	1.00	1.00	1.00	0.98	0.96	0.00	0.00
IL057	823B	0.99	1.00	0.99	1.00	0.76	0.99	0.00	0.00
IL145	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL145	164A	0.94	0.98	0.96	1.00	0.83	0.99	0.00	0.00
IL145	164B	0.94	0.98	0.96	1.00	0.83	0.99	0.00	0.00
IL145	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00

[5] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008. National Commodity Crop Productivity Index (NCCPI), Version 1.0

Taken as a whole, the soil and site factors shown in the table 1(a-ad) are more amenable to corn and soybeans production in Fulton County than in Perry County. This is summarized in Fig. 4 and 5. Figure 4, Fulton County, provides an idea regarding the soil and site factors listed in Table 1(a-d) for growing corn and soybeans on these soils before and after an area is mined. Since the soil factors in Fulton County are often nearly ideal, any change is nearly always negative. Consequently, even a slight change in any of these factors during reconstruction of these mined soils results in failure to achieve the pre-mined NCCPI and probably crop yields on the reconstructed soils. On the other hand, Fig. 5, Perry County, items in Table 1(a-d) illustrates probable substitution or replacement of more desirable thick parent soil material for some of the existing less desirable subsurface soil horizons and applying state-of-the art agronomic and engineering practices increases the possibility of achieving original NCCPI and crop production for reconstructed soils after surface mining activities.

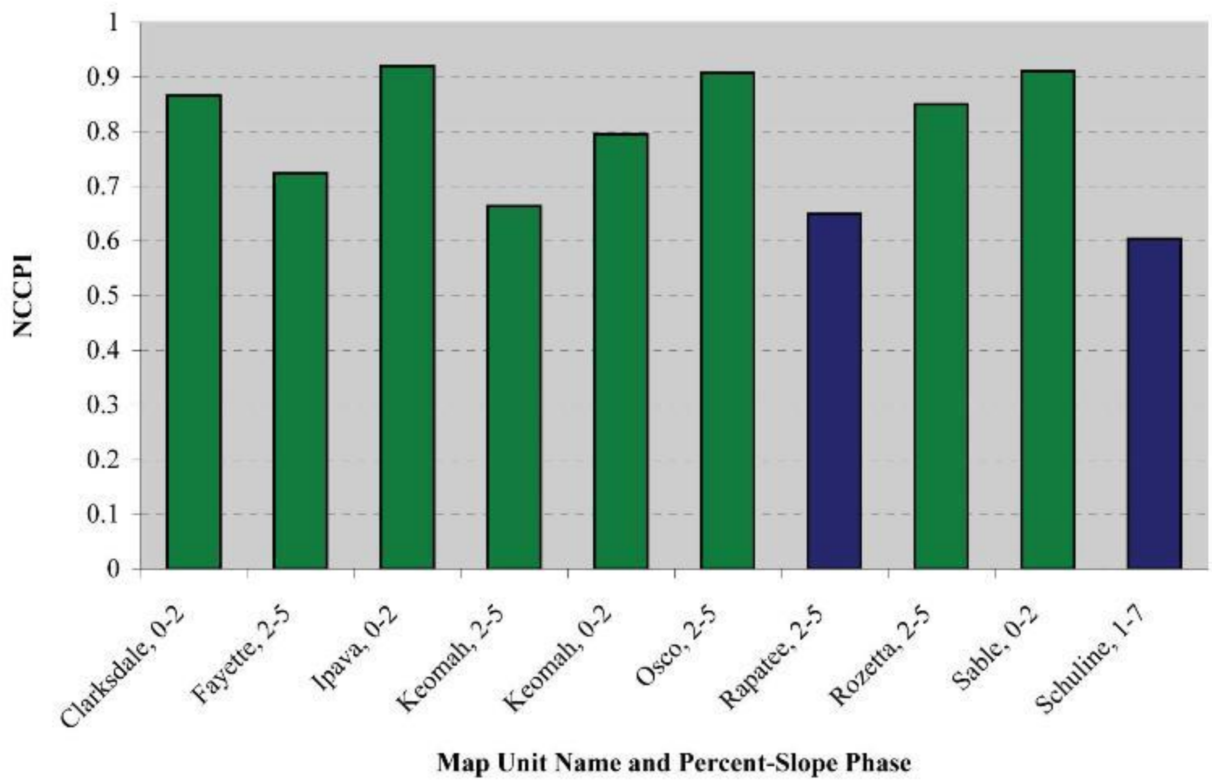

Figure 4. National Commodity Crop Productivity Indices (NCCPI) for Selected Soil Map Units in Fulton County, Illinois. (Green bars are soils that are undisturbed by surface mining for coal. Blue bars are reconstructed soils after surface mining for coal.)

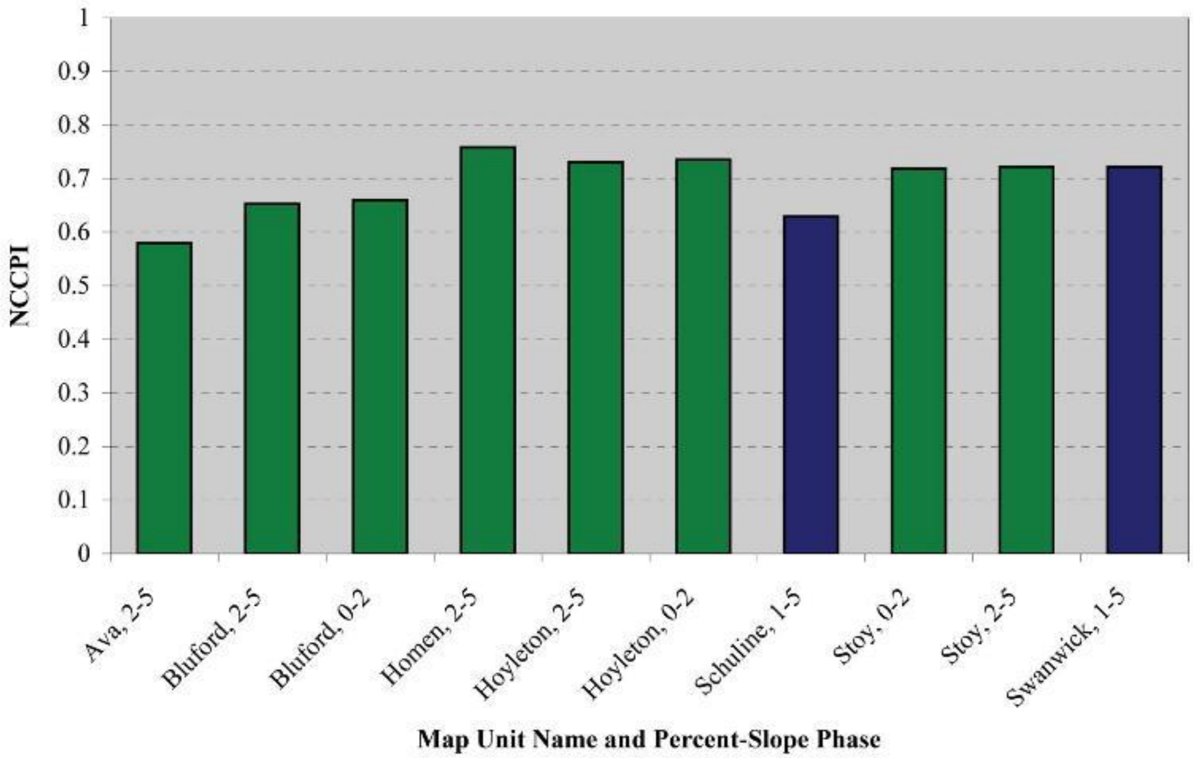

Figure 5. National Commodity Crop Productivity Indices (NCCPI) for Selected Soil Map Units in Perry County, Illinois. (Green bars are soils that are undisturbed by surface mining for coal. Blue bars are reconstructed soils after surface mining for coal.)

The four rows of data highlighted in yellow in Table 1 (a-d) are for the Rapatee, Schuline, and Swanwick soil series which are wholly human-made and are created by reconstruction using soil materials removed from the other (pre-mined) soils shown in the table.

Table 1(b) gives the calculated NCCPI values for 17 pre-mined soils and 4 reconstructed soils. The average NCCPI value for the pre-mined soils is 0.81, while the reconstructed soils have an average value of only 0.65. Taken as a whole, the numerical values shown in the table indicate that the soils are more amenable to corn and soybean production for pre-mined soils than for reconstructed soils. This is summarized in Figures 4 and 5. Figure 4 for Fulton County, shows NCCPI values for prime farmland soils and illustrates how favorable the soil properties, shown in Table 1(a-d), are for crop production on soils such as

Ipava or Osco before surface mining. Thus illustrating, the slightest change in any of these properties during reconstruction of “mined” soils such as Rapatee and Schuline results in disappointment when attempting to achieve the crop yields of the pre-mined soils. Conversely, the NCCPI values shown in Fig. 5 for Perry County, as mentioned earlier, demonstrate that using suitable reconstructed technology after surface mining of coal facilitates achieving crop yields that are comparable to, or exceed the yields of pre-mined soils. For example, the Schuline and Swanwick soils that were constructed in Perry County have NCCPI values (≈0.67) that are similar to pre-mined soils such as Ava and Stoy (≈0.67). These reconstructed soils should have potential yields for corn and soybeans that are comparable to the natural, pre-mined soils.

The irregularly-shaped to elongated, bodies of water shown in Figures 2, 3, 7, and 8 are in areas that in all probability were mined prior to implementation of reconstruction criteria for prime farmland soils in federal regulations (30CFR823. 2008). The NCCPI for these soil areas is less than 0.10.

Table 2(a-d) evaluates the soil and site factors important for growing corn and soybeans on Rapatee, Schuline, and Swanwick soils.

Table 2a. Soil Map Unit Information. Land Capability Subclass, Farmland Designations, and Soil Classification for Rapatee, Schuline, and Swanwick Soils

State and Area Symbol	Soil Map Symbol	Soil name	Surface Texture	Percent Slope	Land Capability Subclass (Non-irrigated)	Important Farmland	Soil Classification
IL057	872B	Rapatee	SICL	2-5	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Alfic Udarents
IL095	872B	Rapatee	SICL	2-5	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Mollic Udarents
IL109	872B	Rapatee	SICL	2-5	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Mollic Udarents
IL143	872B	Rapatee	SIL	1-5	2e	Prime	Fine-silty, mixed, nonacid, mesic Typic Udorthents
IL169	872B	Rapatee	SICL	2-5	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Mollic Udarents
IL175	872B	Rapatee	SIL	1-7	2e	Prime	Fine-silty, mixed, superactive, nonacid, mesic Typic Udorthents
IL045	823B	Schuline	SICL	2-5	2e	Prime	Fine-loamy, mixed, calcareous, mesic Typic Udorthents
IL055	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL057	823B	Schuline	SICL	1-7	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Typic Udorthents
IL077	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL081	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL145	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL157	823B	Schuline	SIL	1-5	2e	Prime	Fine-loamy, mixed, superactive, calcareous, mesic Alfic Udarents
IL169	823B	Schuline	SICL	2-5	2e	Prime	Fine-loamy, mixed, superactive, nonacid, mesic Alfic Udarents
IL077	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL109	824B	Swanwick	SIL	2-5	3e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL145	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL157	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL163	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL169	824B	Swanwick	SIL	2-5	3e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents
IL199	824B	Swanwick	SIL	1-5	2e	Prime	Fine-silty, mixed, active, nonacid, mesic Alfic Udarents

Table 2b. National Commodity Crop Productivity Index (NCCPI), positive/negative attributes, and chemical data for Rapatee, Schuline, and Swanwick Soils. [6] (Soil Survey Staff. 2008b)

Soil Map Symbol	NCCPI 1/ (Index)	Negative Attributes	Frag-ments on Surface Subrule	Erosion Class Subrule	Rock Outcrop Subrule	No Surface Drainage Compo-nent	Degraded Surface Compo-nent	Positive Attributes	Soil Fabric Subrule	Soil Chemical Properties Subrule	RZ CEC Subrule	RZ pH Optimal Subrule	RZ OM Subrule
872B	0.64	0	0	0	0	0	0	0	0	0.79	0.97	0.82	0.99
872B	0.59	0	0	0	0	0	0	0	0	0.78	1	0.79	0.99
872B	0.59	0	0	0	0	0	0	0	0	0.78	1	0.79	0.99
872B	0.63	0	0	0	0	0	0	0	0	0.76	0.97	0.79	0.99
872B	0.59	0	0	0	0	0	0	0	0	0.78	1	0.79	0.99
872B	0.69	0	0	0	0	0	0	0	0	0.76	1	0.79	1
823B	0.51	0	0	0	0	0	0	0	0	0.622	0.97	0.71	0.89
823B	0.63	0	0	0	0	0	0	0	0	0.66	0.987	0.71	0.93
823B	0.60	0	0	0	0	0	0	0	0	0.63	0.99	0.71	0.89
823B	0.63	0	0	0	0	0	0	0	0	0.66	0.98	0.72	0.93
823B	0.63	0	0	0	0	0	0	0	0	0.66	0.98	0.72	0.93
823B	0.63	0	0	0	0	0	0	0	0	0.66	0.98	0.72	0.93
823B	0.63	0	0	0	0	0	0	0	0	0.66	0.987	0.72	0.93
823B	0.67	0	0	0	0	0	0	0	0	0.81	1	0.9	0.89
824B	0.722	0	0	0	0	0	0	0	0	0.92	0.99	0.99	0.93
824B	0.50	0	0	0	0	0	0	0	0	0.64	0.95	0.77	0.88
824B	0.72	0	0	0	0	0	0	0	0	0.92	0.99	0.99	0.93
824B	0.72	0	0	0	0	0	0	0	0	0.92	0.99	0.99	0.93
824B	0.72	0	0	0	0	0	0	0	0	0.92	0.99	0.99	0.93
824B	0.50	0	0	0	0	0	0	0	0	0.64	0.9	0.77	0.88
824B	0.72	0	0	0	0	0	0	0	0	0.92	0.99	0.99	0.93

[6] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008(a). User Guide - National Commodity Crop Productivity Index (NCCPI), Version 1.0.

Table 2c. National Commodity Crop Productivity Index (NCCPI) for Soil Adverse Chemical, Physical, and Landscape Properties for Rapatee, Schiline, and Swanwick Soils. [7] (Soil Survey Staff. 2008b)

Area Symbol	Map Symbol	Soil Adverse Chemical Properties	Root Zone EC Adverse Subrule	Root Zone Gypsum Adverse Subrule	Root Zone SAR Adverse Subrule	Soil Physical Properties Subrule	Ksat Minimum Subrule	Root Zone LEP Subrule
IL057	872B	1.00	1.00	1.00	1.00	0.72	0.79	1.00
IL095	872B	1.00	1.00	1.00	1.00	0.71	0.79	1.00
IL109	872B	1.00	1.00	1.00	1.00	0.71	0.79	1.00
IL143	872B	1.00	1.00	1.00	1.00	0.71	0.79	1.00
IL169	872B	1.00	1.00	1.00	1.00	0.71	0.79	1.00
IL175	872B	1.00	1.00	1.00	1.00	0.88	0.94	1.00
IL045	823B	1.00	1.00	1.00	1.00	0.71	0.77	1.00
IL055	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL057	823B	1.00	1.00	1.00	1.00	0.85	0.90	1.00
IL077	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL081	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL145	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL157	823B	1.00	1.00	1.00	1.00	0.96	0.97	1.00
IL169	823B	1.00	1.00	1.00	1.00	0.83	0.90	1.00
IL077	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95
IL109	824B	1.00	1.00	1.00	1.00	0.70	0.81	1.00
IL145	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95
IL157	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95
IL163	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95
IL169	824B	1.00	1.00	1.00	1.00	0.70	0.81	1.00
IL199	824B	1.00	1.00	1.00	1.00	0.75	0.81	0.95

Table 2c (continued)

Area Symbol	Map Symbol	Root Zone Bulk Density Subrule	Root Zone Rock Fragment Subrule	Root Zone Soil Depth Subrule	Soil Land-scape Subrule	Water Table Subrule	Effective Slope Subrule	Flooding Subrule	Ponding Subrule
IL057	872B	0.93	0.99	0.99	0.99	1.00	0.99	1.00	1.00
IL095	872B	0.93	0.99	0.98	0.99	1.00	0.99	1.00	1.00
IL109	872B	0.93	0.99	0.98	0.99	1.00	0.99	1.00	1.00
IL143	872B	0.93	0.99	0.98	0.99	1.00	0.99	1.00	1.00
IL169	872B	0.93	0.99	0.98	0.99	1.00	0.99	1.00	1.00
IL175	872B	0.95	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL045	823B	0.99	0.98	0.96	0.99	1.00	0.99	1.00	1.00
IL055	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL057	823B	0.96	0.98	1.00	0.99	1.00	0.99	1.00	1.00
IL077	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL081	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL145	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL157	823B	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00
IL169	823B	0.94	0.98	1.00	0.99	1.00	0.99	1.00	1.00
IL077	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL109	824B	0.93	0.99	0.93	0.99	1.00	0.99	1.00	1.00
IL145	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL157	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL163	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00
IL169	824B	0.93	0.99	0.93	0.99	1.00	0.99	1.00	1.00
IL199	824B	0.98	1.00	1.00	0.99	1.00	0.99	1.00	1.00

[7] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008(a). User Guide - National Commodity Crop Productivity Index (NCCPI), Version 1.0.

Table 2d. National Commodity Crop Productivity Index (NCCPI) for Climate and Water Subrules for Rapatee, Schiline, and Swanwick Soils. [8] (Soil Survey Staff. 2008b)

Area Symbol	Map Symbol	Soil Climate Subrule	Frost-Free Days Subrule	Precipi tation Subrule	Water Subrule	RZ AWC Subrule	Precipi-tation Recharge Subrule	Water Table Recharge Subrule	Water-Gathering Surface
IL057	872B	0.98	1.00	0.98	1.00	0.77	0.96	0.00	0.00
IL095	872B	0.91	0.95	0.96	1.00	0.77	0.88	0.00	0.00
IL109	872B	0.91	0.95	0.96	1.00	0.77	0.88	0.00	0.00
IL143	872B	1.00	1.00	1.00	1.00	0.77	0.97	0.00	0.00
IL169	872B	0.91	0.95	0.96	1.00	0.77	0.88	0.00	0.00
IL175	872B	0.94	0.96	0.98	1.00	0.77	0.88	0.00	0.00
IL045	823B	0.94	0.95	0.99	1.00	0.76	0.90	0.00	0.00
IL055	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL057	823B	0.99	1.00	0.99	1.00	0.76	0.99	0.00	0.00
IL077	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL081	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL145	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL157	823B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL169	823B	0.91	0.95	0.96	1.00	0.76	0.88	0.00	0.00
IL077	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL109	824B	0.92	0.95	0.96	1.00	0.75	0.89	0.00	0.00
IL145	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL157	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL163	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00
IL169	824B	0.92	0.95	0.96	1.00	0.75	0.89	0.00	0.00
IL199	824B	0.94	0.98	0.96	1.00	0.82	0.99	0.00	0.00

[8] Dobos, R.R., H.R. Sinclair, and K.W. Hipple. 2008(a). User Guide - National Commodity Crop Productivity Index (NCCPI), Version 1.0.

Figure 6 highlights the importance of developing an adequate agronomic, water, and soil erosion plan prior to reconstruction of mined soils. Development of a rehabilitation plan and maintaining and improving soil and site factors listed in Tables 1 (a-d) and 2 (a-d) will help to comply with the reconstruction rules and regulations for soils after surface coal mining. The plan must allow for disposal of soil materials that produce any undesirable subsurface characteristics as shown in tables 1(a-d) and 2 (a-d) and substitution of more favorable soil parent material as a subsurface rooting media whenever possible.

Table 1(a-d) is a tool to use during the planning and reconstruction of disturbed soils. It's a start, but lets take into account the one thing of foremost concern for growing corn and soybeans or any other commodity crop – water (Dobos et al. (2008(b), Schroeder (1992), Dunker and Jansen (1987), and Stuff and Dale (1973). Enough precipitation to support the crop in reconstructed soils after surface mining for coal must be stored in the reconstructed soils to achieve or exceed original crop production that the tract of land had before mining. In every possible way and to the greatest extent the reconstructed soils must approach root zone available water capacity of 12 inches and must be at or near field capacity throughout the year (Sinclair et al., 2008).

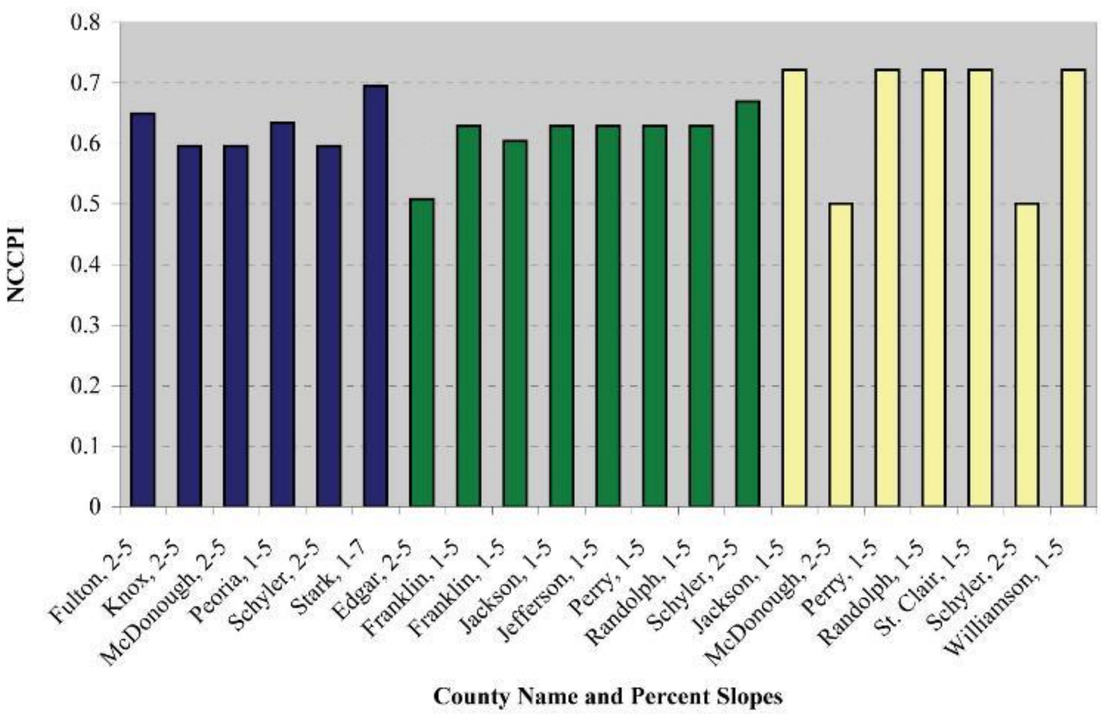

Figure 6. National Commodity Crop Productivity Indices (NCCPI) for 21 Reconstructed Soils in 14 Illinois Counties After Surface Mining for Coal (Blue bars are Rapatee soils. Geen bars are Schuline soils. Yellow bars are Swanwick soils.)

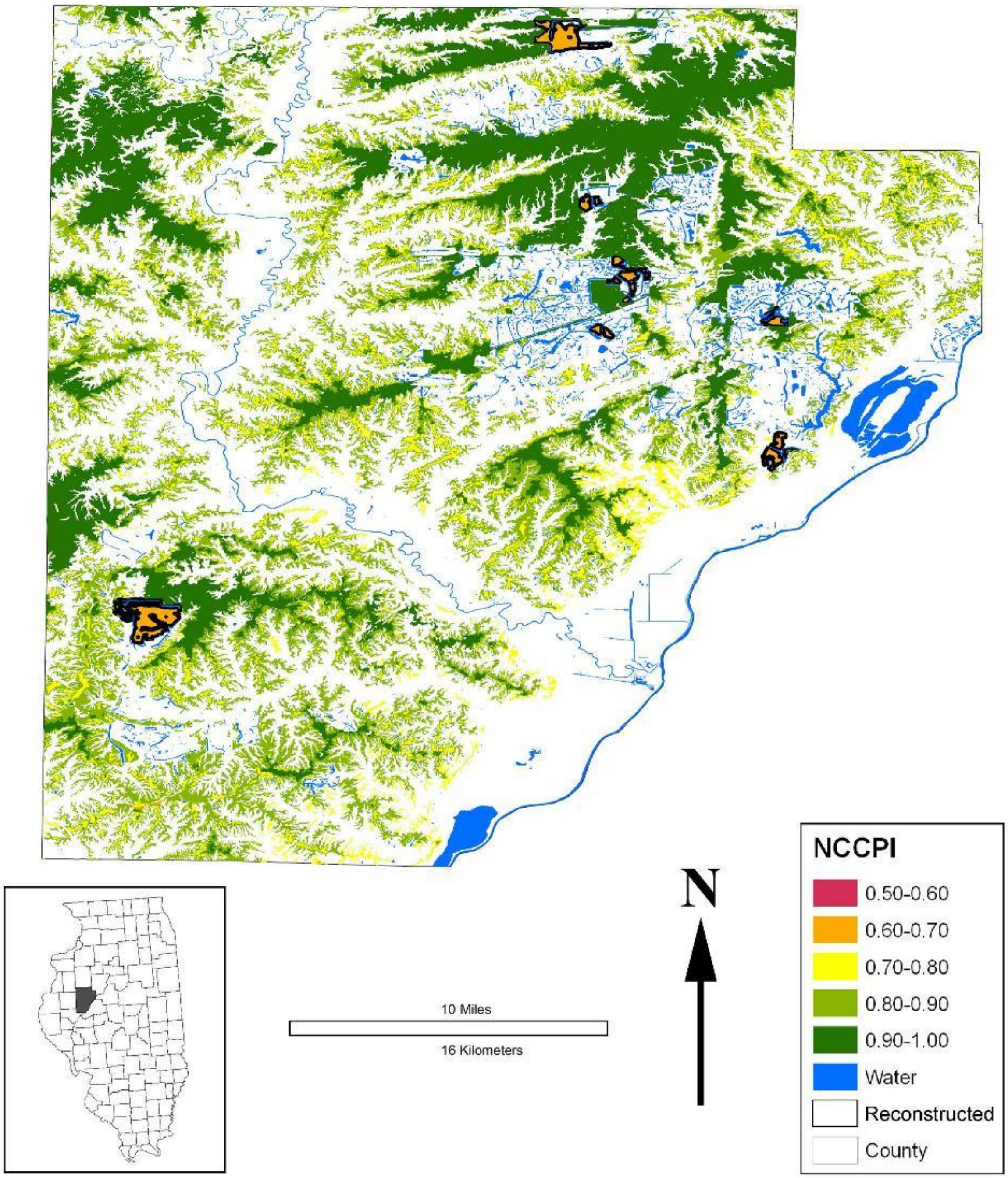

Figure 7. National Commodity Crop Productivity Indices (NCCPI) for Reconstructed Soil Map Units After Surface Mining for Coal Compared to NCCPI of Surrounding Unmined Prime Farmland Soil Map Units in Fulton County, Illinois.

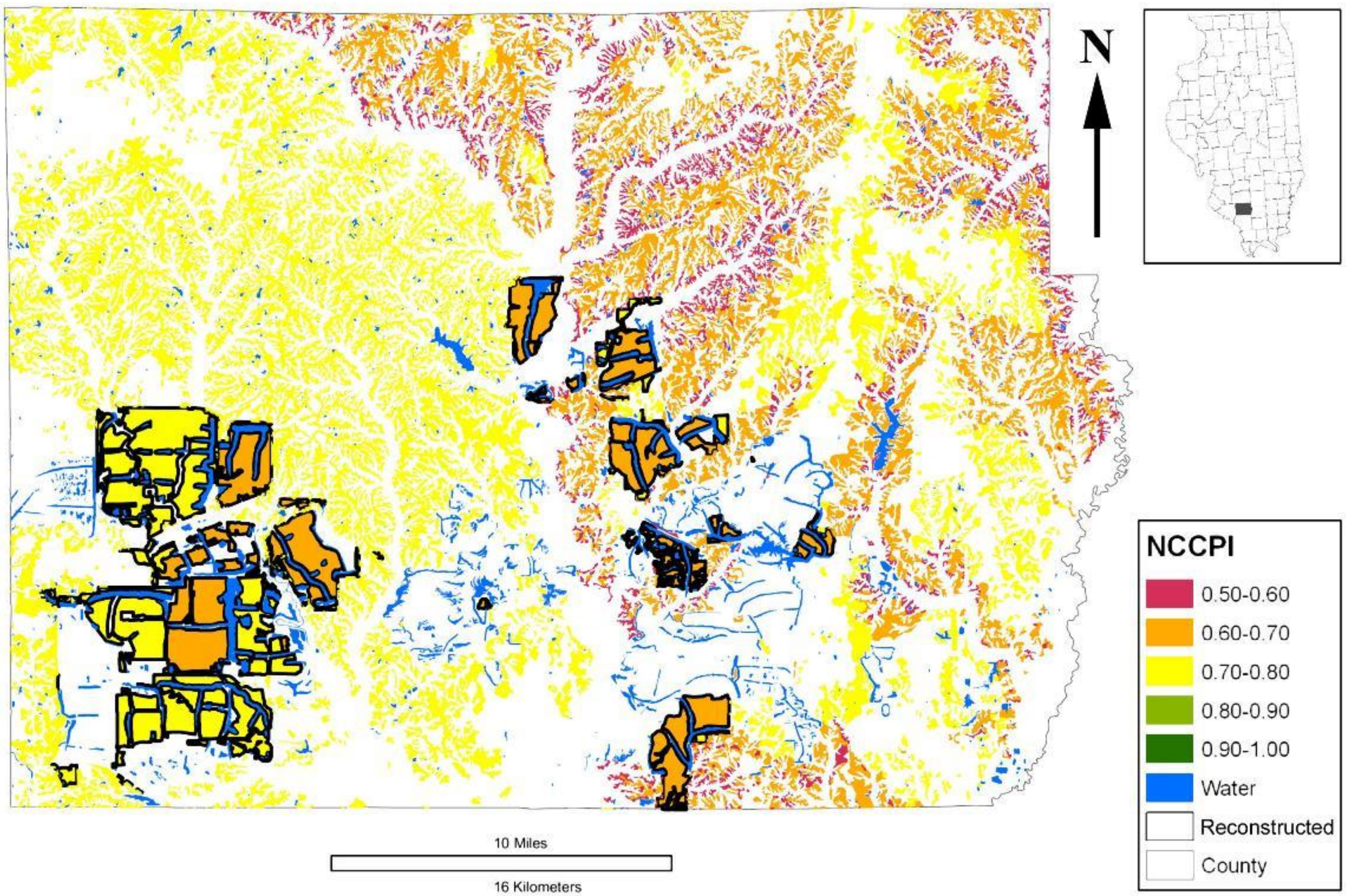

Figure 8: National Commodity Crop Productivity Indices (NCCPI) for Reconstructed Soil Map Units After Surface Mining for Coal Compared to NCCPI of Surrounding Unmined Prime Farmland Soil Map Units in Perry County, Illinois.

Summary

The NCCPI is another tool that can indicate soil, landscape, and climate factors that will influence yields for non-irrigated commodity crops. It is a tool that can assist planners and managers to determine which agronomic and engineering practices to use to maximize RZAWC and control soil erosion to achieve original crop yields during reconstruction of soils after surface mining for coal. It can be used in the "*if*" alternative planning period to evaluate different reclamation options that will result in achieving original or higher crop yields to obtain release of liability bonds. The tool can be used to decide about disposing of undesirable subsurface soil horizons for plant growth and substitution of more favorable soil parent material as subsurface soil rooting media. After surface mining, the reconstructed prime farmland soils should have a positive value for the "water-gathering surface" subrule described in the NCCPI. Figures 7 and 8, Fulton and Perry Counties, show the geographical distribution of NCCPI indices for pre-mined and mined soils in Table 1(a-d). The irregular-elongated-narrow water bodies are in areas that in all probability were mined prior to reconstruction of prime farmland rules and regulation (30CFR823. 2008). The NCCPI indices for reconstructed soils after enactment of 30CFR823 (2008) in Fulton County are lower than the surrounding soils that have not been disturbed by surface mining for coal. In Perry County the NCCPI indices for reconstructed soils after enactment of 30CFR823 (2008) are similar to or lower than the surrounding soils that have not been disturbed by surface mining for coal. Reconstruction criteria for prime farmland soils after surface mining for coal are set forth in federal rules and regulations (30CFR823, 2008). The present federal law requires that soils designated as prime farmland be reconstructed back to cropland with yields equal to or greater than the pre-mined soil.

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