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Natural
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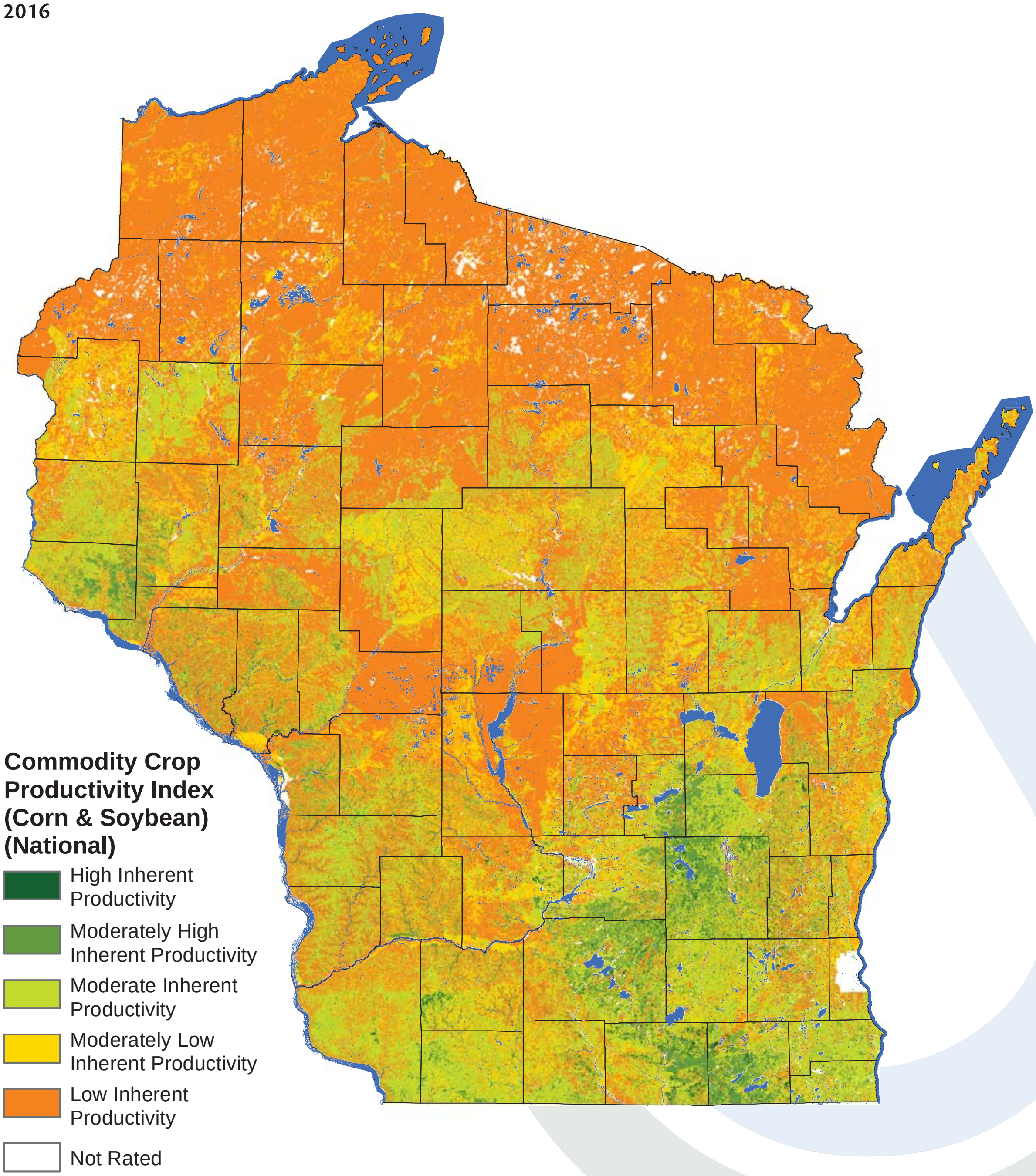
April 2016

An Introduction to Fuzzy Systems

Soil Interpretations

A Look Into the Wisconsin Crop Index



Abstract

An introduction to soil interpretations and basic concepts, including the Fuzzy System. This paper also gives tips and tricks for creating successful soil interpretations and introduces the Wisconsin Commodity Crop Productivity Index.

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INTRODUCTION TO SOIL INTERPRETATIONS

- Soil Interpretations are models used to predict soil behavior under a set of defined criteria
- Soil property data in the database is used to produce ratings; thus, if data does not reflect the soil component properly, the rating will not be appropriate.
- The fuzzy number is an indicator of the degree of membership a component has in the set of limited components, in limitation-style interpretations: 1.00 means a full member, 0.00 means a non-member. In a suitability style interpretation, 1.00 means well suited and 0.00 means not suited.

Basic Concepts of the Fuzzy System

The basic concept of fuzzy systems is plotting values on a graph, which is indicated in truth values (in fuzzy logic) or membership function (in fuzzy sets). Numerical values are shown in decimal fractions ranging from 0.01 to 1.00.

For example, in Fig. 1, a fuzzy set is a set of tall people. Let's say our range of height is from 3 ft to 8 ft. The word "tall" corresponds to a curve on a graph in which any person is tall. If "tall people" was defined, a classic set would be "crisp-hard breaks." In a fuzzy system, the numbers would be arrayed. Now let's use Bill as an example (Fig. 1).

"Bill is tall."

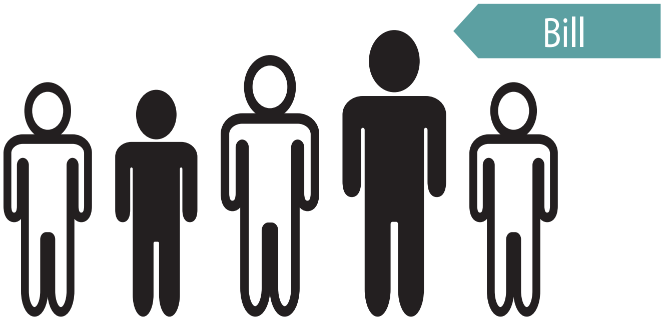


Figure 1. An example of a fuzzy set, or a set of tall people.

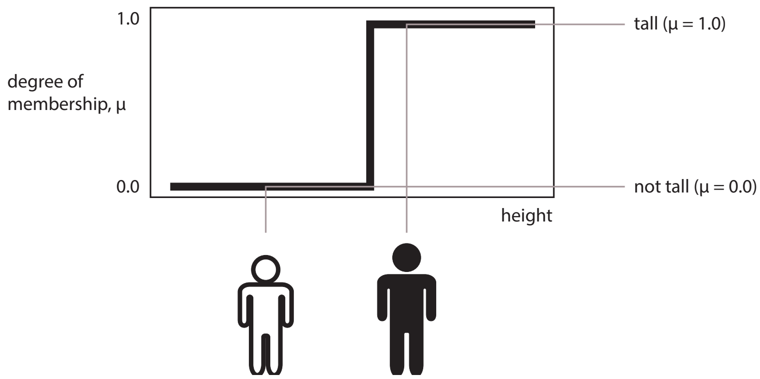


Figure 2. Illustration of a classic set with crisp-hard breaks.

If Bill's height is 6 ft 5 in, we might assign a statement where the truth value is 0.75 (Fig. 2). The statement could be translated into set terminology as follows:

"Bill is a member of the set of tall people."

The statement would be symbolized with fuzzy sets as:

Membership Function (*m*) of Bill = 0.75

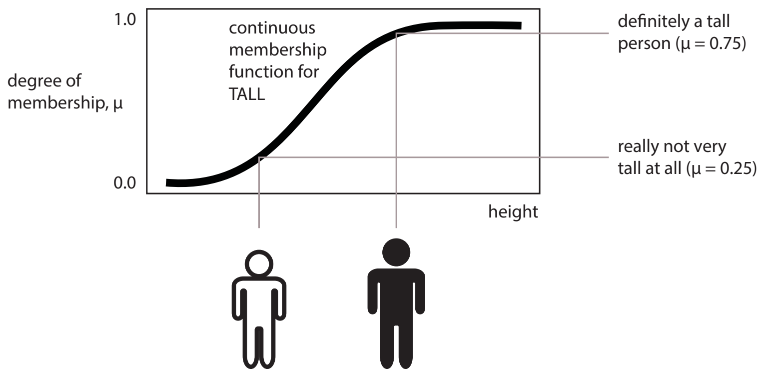


Figure 3. The output-axis is a number known as the membership. value between 0 and 1.

In Fig. 3, the curve is known as a membership function and is often given the designation of *m*. This curve defines the range from not tall to tall. Both people are tall to some degree, but one is significantly less tall than the other.

The membership function (*m*), operating in this case on the fuzzy set of tall people, returns a value between 0.0 and 1.0.

It is important to note that there is a distinction between "fuzzy systems" and "probability statistics." Both have essentially the same numeric range, and have similar values, 0.0 representing false (or non-membership) and 1.0 representing true (membership). However, there is a difference between the two. The "probability statistics" approach would state "there is a 75% chance that Bill is tall," while the fuzzy math terminology corresponds to "Bill's degree of membership within the set of tall people is 0.75."

The difference between a fuzzy system and statistics is significant.

- » The "probability statistics" view supposes that Bill is or is not tall and there is a 75% chance of knowing which set he is in.
- » The fuzzy system supposes that Bill is "more or less" tall, or some other term corresponding to the value of 0.75.

Rules for Developing a Soil Interpretation

1. Change interpretive rules to fit properties instead of modifying soil properties to fit interpretations. Do not change data to make interpretations better.
2. Avoid using categories for developing interpretations such as drainage class.
3. Avoid using properties that can redundantly overlap in other areas.
4. Avoid using one interpretation as a criteria for developing other interpretations. Similarly, avoid other interpretations as criteria for developing a new interpretation.
5. A good interpretation speaks for itself. Avoid post editing an interpretation's rating and overriding the results to address a problem. This does not fix the overall interpretation. Data would need to be manually updated one-by-one every update. Manually updating data may cause greater errors in the interpretation.
6. Add classes to the main rule at the end, instead of putting classes on sub-rules.
7. Avoid using hard breaks and use an array of numbers. Adding hard breaks to the soil properties will skew the interpretation.

Understanding the Difference Between Soils Data and an Interpretation

Let's imagine you're setting up a bakery specializing in making cakes. In Fig. 4, the fresh flour represents official soils data (one important ingredient); the finished cakes represent soil interpretations. If the cake turns out tasting poorly, you wouldn't change the fresh flour, you'd first look at changing the overall recipe instead. The fresh flour is the raw material, or base that holds the cake together; it is one important ingredient of the recipe. Similarly, current official soils data is the base ingredient to a good, solid interpretation. If you are an external user developing interpretations, keep in mind that your model might not turn out as desired the first time. You might need to modify the model several times to get desired results and use actual data (if available) to calibrate results. The fresh flour (or official soils data) is all-purpose, having many uses for different interpretations and fields. Using fresh flour, or the most updated, official soils data correctly, makes a big difference in the quality of your baking creation or soils interpretation.

Figure 4. A good analogy: Flour (like official soils data) is an important ingredient to a cake (like interpretations).

Exploring the Meaning of Limiting Features in the Context of a Land Use

Consider a simple example of evaluating a site for the construction of a picnic area. It might be determined that "a site has limitations for picnic areas if it is too wet or too steep" (limitation). On the contrary, it might be determined that "a site has no limitations for picnic areas if it is not too wet or too steep" (suitability).

After articulating the interpretive statement, the definitions of "too steep" and "too wet" in the context of picnic areas must be determined. As an expert, or preferable, as a team of experts, there may be a variety

Limitations for Picnic Areas

Property	Not Limited	Somewhat Limited	Very Limited	Restrictive Feature
				too steep
				too wet

Table 1. Template for defining the meaning of limiting features.

Limitations for Picnic Areas

Property	Not Limited	Somewhat Limited	Very Limited	Restrictive Feature
Slope (%)	< 8%	8 - 15%	> 15%	too steep
Depth to saturation (cm)	> 100	20 - 99	< 20	too wet

Table 2. Definitions of limiting features for picnic areas.

of meanings to consider. Table 1 is a template for filling in the meanings determined for each limiting feature.

The meaning of "too steep"

What property would be evaluated in determining whether a soil is too steep for a picnic area? Slope is the most likely property to evaluate.

The next step is to consider the class limits for slope. A picnic area, based on requirements, may include a wood or a concrete table with a bench and a fire pit. It might be concluded that a slope of less than 8% would indicate a site is Not Limited, a slope of 8% to 15% Somewhat Limited, and any slope greater than 15% Very Limited. These values are entered into the template, as shown in Table 2.

The meaning of "too wet"

Determining a property for "too steep" was fairly straightforward. However, wetness can be measured in a variety of ways: depth to wet layer, available water capacity (AWC), texture, or soil moisture in the surface layer. Each property might be valid given the land use of picnic areas. Therefore, what is meant by picnic areas and their expected use must be further defined. Will the picnic area be paved or gravelled, seeded to turf grasses or in a forest cover? What months of the year will it be used? And so on.

Any of the properties mentioned could be used. For this demonstration, minimum depth to soil zone of saturation will be used. Given expert knowledge on the land use and requirements, it is determined that a depth to saturation greater than or equal to 100 cm indicates a site is Not Limited, a depth between 20-99 cm Somewhat Limited, and a depth of less than 20 cm Very Limited. These values are entered into the template, as shown in Table 2.

Table 2 is similar to the historical rating guides used for interpreting soils prior to the SSURGO (Soil Survey Geographic database.) The rating classes of Not Limited (slight), Somewhat Limited (moderate), and Very Limited (severe) are referred to as "crisp" limits or defined class breaks.

The Limitation of Using "Crisp Limits"

The main limitation in the use of rating classes, or crisp limits, is that they do not always indicate a fine enough distinction of gradation. For example, referring to Table 2 above, crisp rating classes define both 8% and 15% slope as making a site Somewhat Limited limitations for picnic areas. Consider that the 15% slope is categorized as Somewhat Limited whereas the 16% slope is categorized as Very Limited. Therefore, a wide variation of slopes between 8 and 15% get the same rating, however slopes that are nearly the same, 15% and 16%, get different ratings. Given this limitation of defined classes, the fuzzy logic approach is used to rate affecting features using numerical values instead of rating classes.

Introducing Fuzzy Logic

What if the evaluation of a property was continuous? What if the degree of limitation increased continuously as slope increased or as the soil saturation rose closer to the surface? The use of fuzzy logic makes this possible. The fact that something is true does not exclude the possibility that it is also false. Fuzzy logic is built upon the precept of approximate reasoning. With fuzzy logic, a complete gradation of the truth (or falseness) of the interpretive statement can be represented.

Fuzzy logic provides a translation of the ranges of properties into a uniform basis. The uniform basis is a value from 0 to 1, where 1 means a statement is absolutely true and 0 means a statement is absolutely not true. For example,

The slope percentage for picnic areas is rated as:

< 8 Not Limited

8-15 Somewhat Limited

> 15 Very Limited

The minimum depth to water table is rated as:

> 100 Not Limited

20-99 Somewhat Limited

< 20 Very Limited

With fuzzy logic, a value in the middle or anywhere along a continuum can be identified. The easiest method to see this continuum is to set up a graph. Notice that in Figs. 5 and 6 the values for slope and minimum depth to water table are translated into some measure of truthfulness about the statement of being too wet or too steep. (In this simple example, a sigmoid curve will be used.)

With fuzzy logic, a value in the middle can be shown. It is partly true that 10% slope is too steep. It's also partly not true.

With fuzzy logic, a value in the middle can be shown. It is partly true that a 55-cm depth is too wet. It's also partly not true.

Compare the graphs in Figs. 5 and 6 to Table 2. The difference is that instead of crisp limits, there are now gradational limits. To understand the improvement in the interpretive criteria, there must be an understanding in fuzzy math concepts.

Although, in this demonstration, the numerical values for too steep and too wet seem determined, the values would actually be based on known data or opinions of experts creating the interpretation. When the numerical values for too steep and too wet are determined, the possibilities of dealing with interactions and relative weights become real.

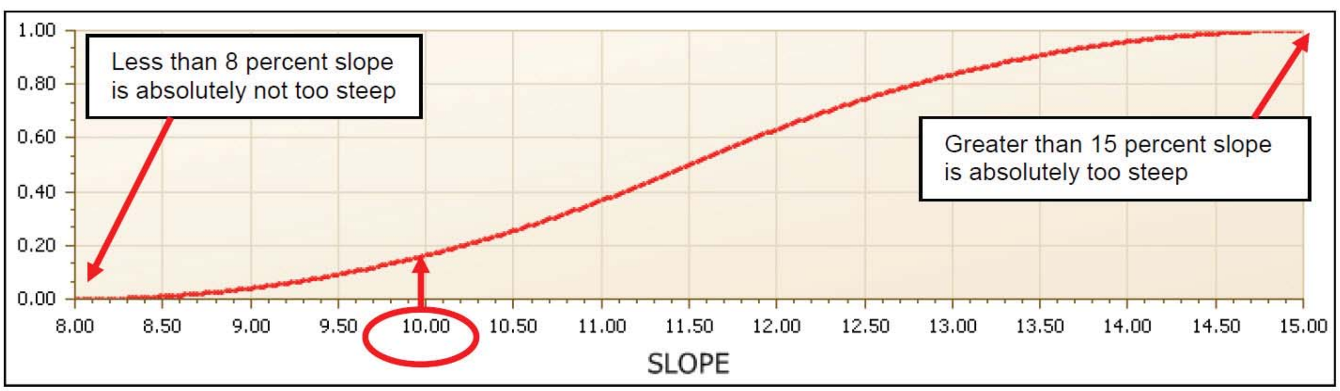


Figure 5. Percent slope along a continuum.

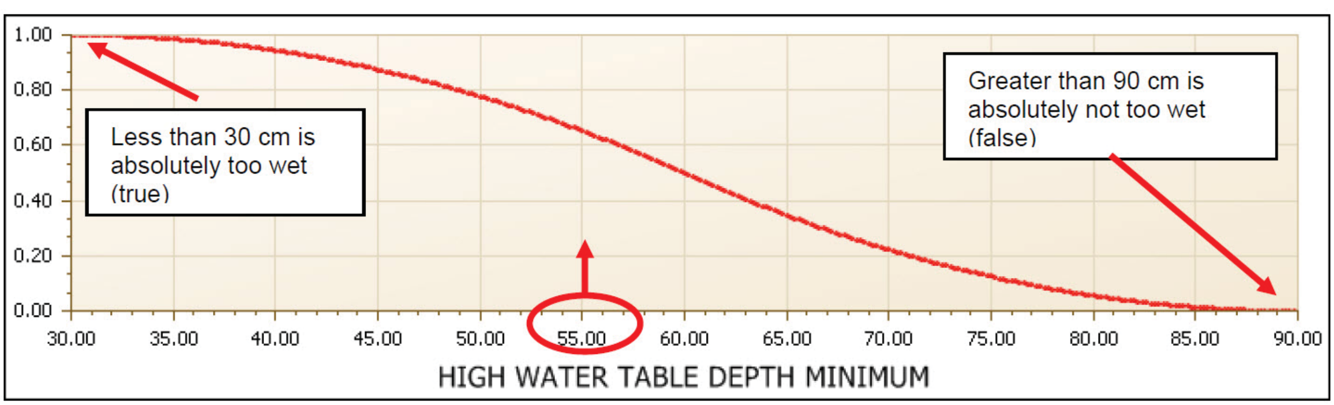


Figure 6. Minimum depth to water table along a continuum.

Understanding Fuzzy Math Concepts

Applying fuzzy math allows soil interpretations to handle interactions. For example, in interpretations using the interaction of slope and soil saturation, water decreases can be evaluated as slope increases. Fuzzy logic allows the use of relative weights, such as providing slope with more importance to the interpretation than depth to saturation.

Consider the conventional method of thinking. As stated previously, the fact that something is true does not exclude the possibility that it is also false, although the conventional bias is to believe that true excludes false. In the conventional way of thinking, a statement of A OR B is TRUE under the first three conditions in Tables 3 and 4. The statement of A OR B is FALSE under the last condition:

if A is true OR	if B is true THEN	the condition is true
T	T	T
T	F	T
F	T	T
F	F	F

Table 3. Conventional math concepts.

In order to use fuzzy math, there must be an understanding of the logic that it uses.

Fuzzy Math		
A or B	≈	Max [A, B]
A AND B	≈	Min [A, B]

Table 4. Conventional math concepts.

OR Operator

Table 5 shows a truth table for the Boolean **OR** operator. Using fuzzy math, the true values are equal to 1 and the false values are equal to 0. By inserting the fuzzy values of 0 to 1 and then applying the fuzzy math rule of A OR B ~ Max [A, B], the conditions are expressed for the OR statement.

The table demonstrates with true=1 and false=0 that **OR** is equivalent to **Max**.

if A is true OR	if B is true THEN	the condition is true
T (1)	T (1)	T (1)
T (1)	F (0)	T (1)
F (0)	T (1)	T (1)
F (0)	T (1)	F (0)

Table 5. Fuzzy math using OR operator.

AND Operator

Table 6 shows a truth table for the Boolean **AND** operator. Using fuzzy math, the true values are equal to 1 and the false values are equal to 0. By inserting the fuzzy values of 0 to 1 and then applying the fuzzy math rule of A AND B ~ Min [A, B], the conditions are expressed for the AND statement.

This table demonstrates with true=1 and false=0 that **AND** is equivalent to **Min**.

if A is true AND	if B is true THEN	the condition is true
T (1)	T (1)	T (1)
T (1)	F (0)	F (0)
F (0)	T (1)	F (0)
F (0)	F (0)	F (0)

Table 6. Fuzzy math using AND operator.

This demonstration of fuzzy math is not meant as a proof but simply as a demonstration of how the math works. Returning to the picnic area example, insert into the equation the fuzzy values shown in the graphs in Figs. 7 and 8.

Remember the interpretive statement and apply the fuzzy values from the graphs above. Refer to Fig. 6 below for a picture of how it fits together.

Finally, compute the interpretive result given the OR operator:

A site has limitations for picnic areas if the site is 0.6 too steep or the soil is 0.4 too wet. Because the statement has an OR condition, the fuzzy rule of A OR B ~ Max [A, B] was applied to produce the maximum value of 0.6. With fuzzy logic, there is a 0.6 truthfulness that the site has limitations for picnic areas and that the primary limitation is related to slope.

What is the result if the statement of limitations was constructed as “A site has limitations for picnic areas if it is too wet AND too steep?” Using the math for AND statements the result would be a 0.4 truthfulness that the site has limitations for picnic areas.

A	OR	B	Then (max)
T.6		T.4	T.4

Table 6. Statement of limitations results.

Is it good or bad that there is a 0.4 truthfulness that the site has limitations for picnic areas and that the limitation relates to the interaction of slope and wetness? Furthermore, what does the numerical value mean? How does the numeric value relate to the interpretive statement for picnic areas? These questions depend on the opinion and judgment of an expert or team of experts.

Fuzzy logic provides the ability to handle interactions and relative weights to interpret a soil property, but expert opinion and judgments are necessary when assigning meaning to the fuzzy numbers. The decision on the values meaning in the context of the land use is decided by the experts.

Converting the Fuzzy Result to Rating Classes (Defuzzifying)

The soils database provides the option of assigning conventional rating classes as well as rating values (fuzzy values). Any number of rating values between 0 and 1 can be created and assigned rating classes. Expert opinions and judgments are the basis of the adjectives used and the values assigned to the rating classes.

Using the ongoing example of picnic areas, where the rating value for slope is .6 and the rating value for wetness is .4, applying the OR operator gives an overall rating of .6.

A - If slope is 11.85 percent, then the fuzzy value is 0.60

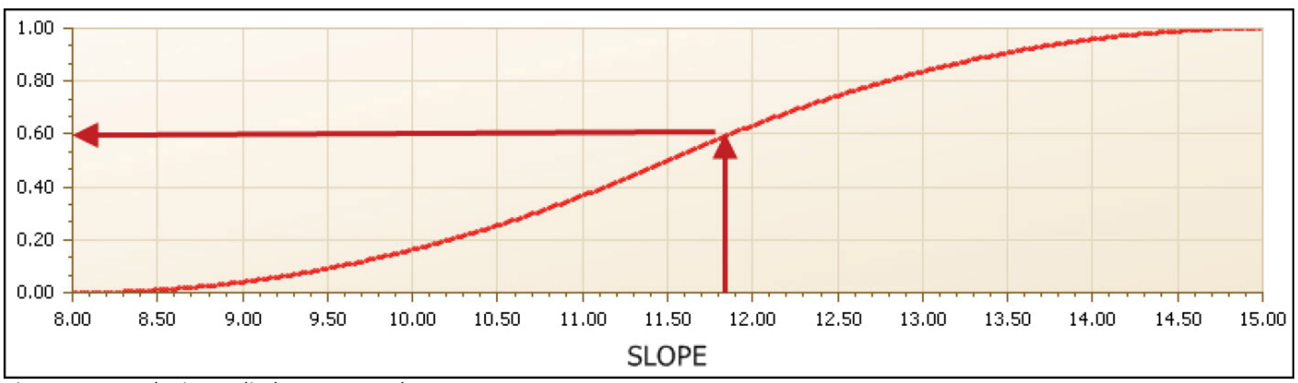


Figure 7. Fuzzy logic applied to percent slope.

B - If the soil is saturated at 63 cm, then the fuzzy value is 0.40

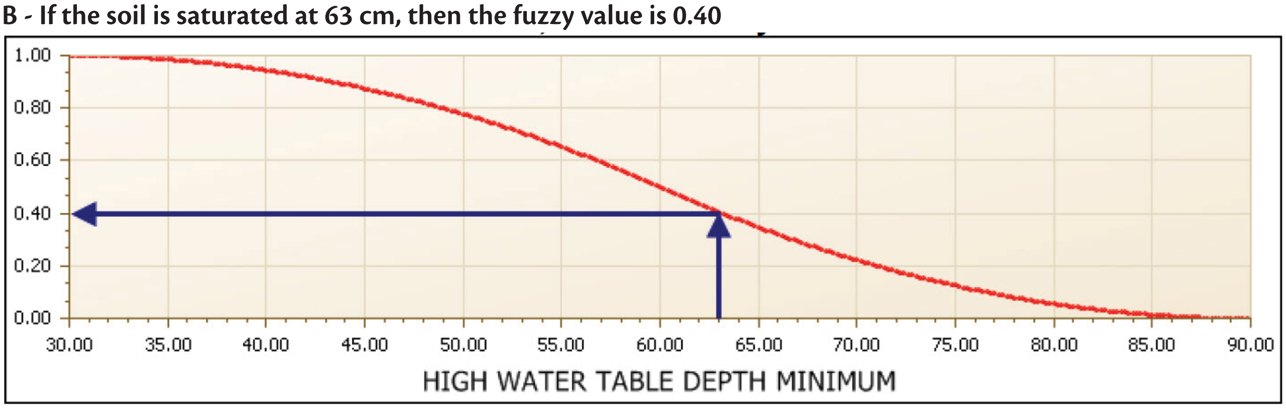


Figure 8. Fuzzy logic applied to minimum depth to soil saturation.

Source: Chapter 19, NRCS Soil Interpretations

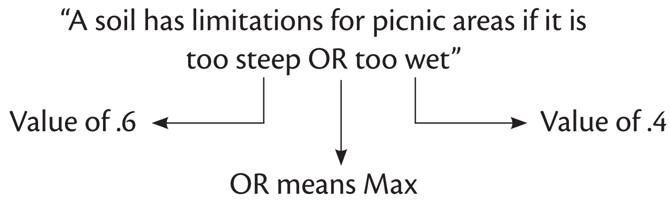


Figure 6. Interpretive statement with fuzzy values for picnic areas.

Rating Classes

Not limiting	0.4
Somewhat limiting	0.6
Limiting	0.75
Very limiting	0.99
Extremely limiting	1.0

Understanding how to read the fuzzy result in terms of rating classes is important yet may not be apparent. When entering rating classes, enter the maximum rating value associated with each range. In Table 7,

» a value greater than 0 and less than .4 is not limiting;
» a value greater than .4 and less than .6 is somewhat limiting;
» a value greater than .6 and less than .9 is limiting;
» a value greater than .9 and less than 1 is very limiting; and
» a value equal to 1 is extremely limiting.

Historic Additive Systems

Soil scientists in Wisconsin (Berger et al., 1952), Iowa (Fenton et al., 1971), Indiana (Walker, 1976), and Oregon (Huddleston, 1982) have calculated productivity ratings from additive systems. In each case, several soil properties were assigned numerical values according to their inferred impact on plant growth. These numbers were either summed up, or they were subtracted from a maximum rating of 100 to derive a final rating. Most of these rating systems were not purely inductive, as crop yield data were used either directly or indirectly to establish standards of performance for calibration of ratings induced from soil factors.

Additive systems have the advantage of being able to incorporate information from more soil properties than multiplicative systems (see Fig. 9). Four or five factors seems to be a practical limit for multiplicative systems; otherwise, most ratings are so low that the approach cannot distinguish small differences in productivity.

Additive systems allow the consideration of many more criteria, both singly and in combination with the effects of other factors. Other advantages are that no single factor can have enough weight to unduly influence the final rating, and it is generally easier to specify criteria exactly for unambiguous determination of factor values and soil productivity ratings. The type of Interpretation for the Wisconsin Commodity Crop Index is a suitability based on an additive system.

Excerpt from Huddleston, 1984. See references.

AN INTRODUCTION TO WICCPI

The Wisconsin Commodity Crop Productivity Index (WICCPI) arrays soils according to their inherent capacity to produce dryland (non-irrigated) commodity crops in Wisconsin. Most of the WICCPI criteria relate directly to the ability of soils, landscapes, and climates to foster crop productivity. Fluctuations in productivity caused by good or bad management and year-to-year variations in weather are not addressed. The Wisconsin crop index model is based on an additive system that sums all the rules together. If conditions are perfect, the overall rating will equal one.

Background

- Much of the yield data in the soil database is out of date or is null
- Existing yield data are inconsistent and from different vintages and management

Purpose

- Replace stored crop yields
- Produce consistent statewide crop production index
- Better reflect local conditions
- Improve statewide planning

Why the WICCPI?

Productivity indices have the advantage of being less vulnerable to changes in technology than expressions of productivity based on yield (see Table 7). A mechanism that determines soil productivity in Wisconsin consistent across political boundaries and over time is needed for many uses. Crop varieties, management

Wisconsin Commodity Crop Productivity Index for Corn

(WICCPI) Interpretation (Suitability): Additive System

What's Ideal for Wisconsin?

Property	Criteria (Ideal for Wisconsin)	Explanation
Organic Matter	Surface (3%) and subsurface (1%)	High natural fertility; responds well to fertilization and liming; high surface and subsurface organic matter
Cation Exchange Capacity	surface (24 meq/100g) and subsurface (20 meq/100g)	High surface and subsurface cation-exchange capacity (CEC/ECEC)
pH (H_2O)	Subsurface pH (5.9-7.6 in 1:1 H_2O)	Subsurface pH near neutral
Depth to Restrictive Feature	(>150 cm)	Unlimited root penetration; no rooting barriers (e.g., bedrock)
Wetness	April & May (60-80 cm)	Adequate but not excessive soil water; not too wet, not too dry (e.g., May)
Depth to Ksat	(1.39 to 42 um/s)	The ease in which pores of a saturated soil transmit water (water movement)
Available Water Capacity	soil depth from: 0-20 cm, 3.9 cm/cm	Excellent available water capacity in surface and subsurface
	20-60 cm, 7.95 cm/cm	
	60-100 cm, 7.95 cm/cm	
	100-150 cm, 9 cm/cm	
Ponding and Flooding Frequency & Duration	April & May	Not subject to flooding or ponding (e.g., April/May)
Slope	Nearly level (slope percent)	
Water Balance	Water balance: monthly rainfall divided by potential evapotranspiration (PET)	

Table 7. Criteria for Wisconsin Commodity Crop Productivity Index (WICCPI) for corn.

scenarios, and yields vary from place to place and over time, reflecting choices made by farmers. These factors partially mask inherent soil quality. Except for extreme circumstances, inherent soil quality or inherent soil productivity varies little over time or from place to place for a specific soil (map unit component) identified by NRCS soil surveys.

Depths for data entry for many of these properties are based on typical rooting depths for corn. For example, over 90% of corn roots are found in the upper meter of the soil. Over the growing season, about 70% of water used by corn will come from the first 60 cm. Extraction is most rapid in the zone of greatest root concentration and where the most favorable conditions of aeration, biological activity and nutrient availability occur. Therefore, properties are weighted heavily for conditions found in the upper meter of the soil.

These properties quantify the effects of pH, CEC, and organic matter in the root zone, which is the zone from the soil surface to a depth of 100 cm or more or to a root-limiting layer. The effects of pH are considered for depths of 20 cm to 100 cm. Organic matter also is

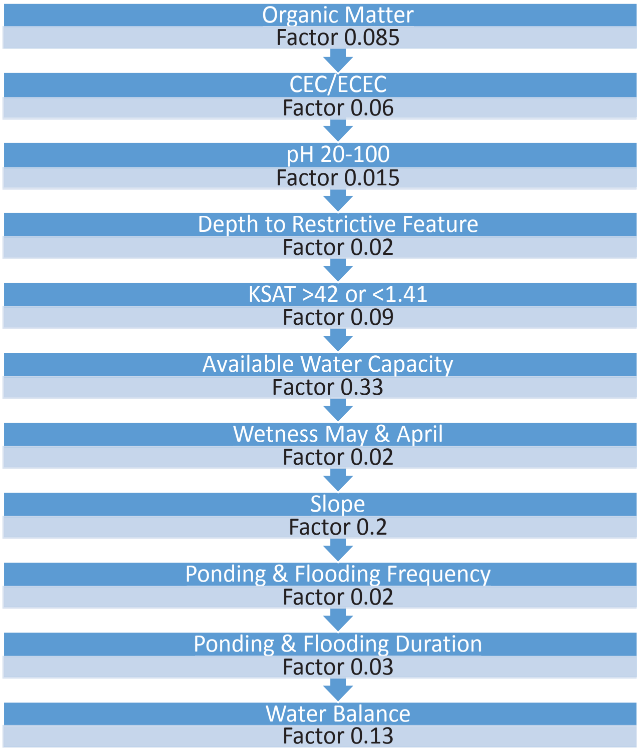


Figure 9. Additive system each factor is summed to 1.

considered for the depth ranges of 0 to 20 cm and 20 to 100 cm. The average condition is used in the interpretation. Properties also quantify the effects of Ksat and soil depth on soil productivity. The Bedrock property examines the thickness of soil material over bedrock. Layers with Ksat greater than 1.39 and less than 42.0 micro m/sec correlate well in the database with some characteristic that impedes roots such as bulk density, linear extensibility, etc. Saturated hydraulic conductivity (Ksat) is a measure of the ease of water movement in soil. It can reasonably be assumed that it also is an indicator of the ease of air movement. Although the arrangement and size distribution of pores can greatly affect Ksat, it correlates well with ease of root movement.

Properties also quantify the capability of the soil, climate, and landscape to supply water for crop growth. Soil moisture availability is determined by the interaction of four factors: (1) amount of moisture present in the soil, (2) characteristics of the soil profile, (3) moisture capacity of the crop, and (4) demand for water by the atmosphere.

Root zone available water capacity (AWC) is the amount of plant-available water a soil can store between the surface and a root-limiting layer or between the surface and a depth of 150 cm, whichever is less. In this interpretation, four layers are evaluated for AWC: 0 to 20 cm, 20 to 60 cm, 60 to 100 cm, and greater than 100 cm.

The WICCPI uses the properties of slope gradient; depth to a water table during the growing season; and the occurrence, timing, and duration of ponding and flooding during part of the growing season in calculating crop productivity index.

The Wetness/May property quantifies the effects of a saturated zone deep within the zone where roots can exploit water during parts of the growing season. It also quantifies the detrimental effects of a water table at or near the surface, i.e., delays to planting or stress on crops early in the growing season.

Climate conditions in June, July, and August are good indicators of a soil's productivity for corn and soybeans. Rainfall and temperature during this timeframe greatly affect crop productivity. The impact of rainfall for a given area is decreased because of the effects of temperature, day length and latitude, and crop use. For example, consider two soils, both receiving the same amount of rainfall. One soil is hot, thermic, while the other is cool, mesic. A larger amount of rainfall on the cooler site is more readily available for crop growth due to lower evapotranspiration rate, and so the cool, mesic site receives a higher water balance value.

The ratings are both verbal and numerical. Rating class terms indicate the estimated productivity which is determined by all of the soil, site, and climatic features that affect crop productivity.

Rating Class Name	Rating Value
High inherent productivity	0.91 - 1.00
Moderately high inherent productivity	0.81 - 0.9
Moderate inherent productivity	0.51 - 0.8
Moderately low inherent productivity	0.41 - 0.5
Low inherent productivity	0.01 - 0.4

Table 8. Fuzzy Index range for Rating Classes

High inherent productivity *indicates that the soil, site, and climate have features that are very favorable for crop production. High yields and low risk of crop failure can be expected if a high level of management is employed.*

Moderately high inherent productivity *indicates that the soil has features that are generally quite favorable for crop production. Good yields and moderately low risk of crop failure can be expected.*

Moderate inherent productivity *indicates that the soil has features that are generally favorable for crop production. Good yields and moderate risk of crop failure can be expected.*

Moderately low inherent productivity *indicates that the soil has features that are generally not favorable for crop production. Low yields and moderately high risk of crop failure can be expected.*

Low inherent productivity *indicates that the soil has one or more features that are unfavorable for crop production. Low yields and high risk of crop failure can be expected.*

Numerical ratings indicate the overall productivity of the soil. The ratings are shown in decimal fractions ranging from 1.00 to 0.01. They indicate gradations between the point at which the combination of soil, site, and climate features has the greatest positive impact on inherent productivity (1.00) and the point at which the soil features are very unfavorable (0.01).

The map unit components listed for each map unit in the accompanying Summary by Map Unit table in Web Soil Survey or the Aggregation Report in Soil Data Viewer are determined by the aggregation method chosen. An aggregated rating class is shown for each map unit. The components listed for each map unit are only those that have the same rating class as listed for the map unit. The percent composition of each component in a particular map unit is presented to help the user better understand the percentage of each map unit that has the rating presented.

Other components with different ratings may be present in each map unit. The ratings for all components, regardless of the map unit aggregated rating, can be viewed by generating the equivalent

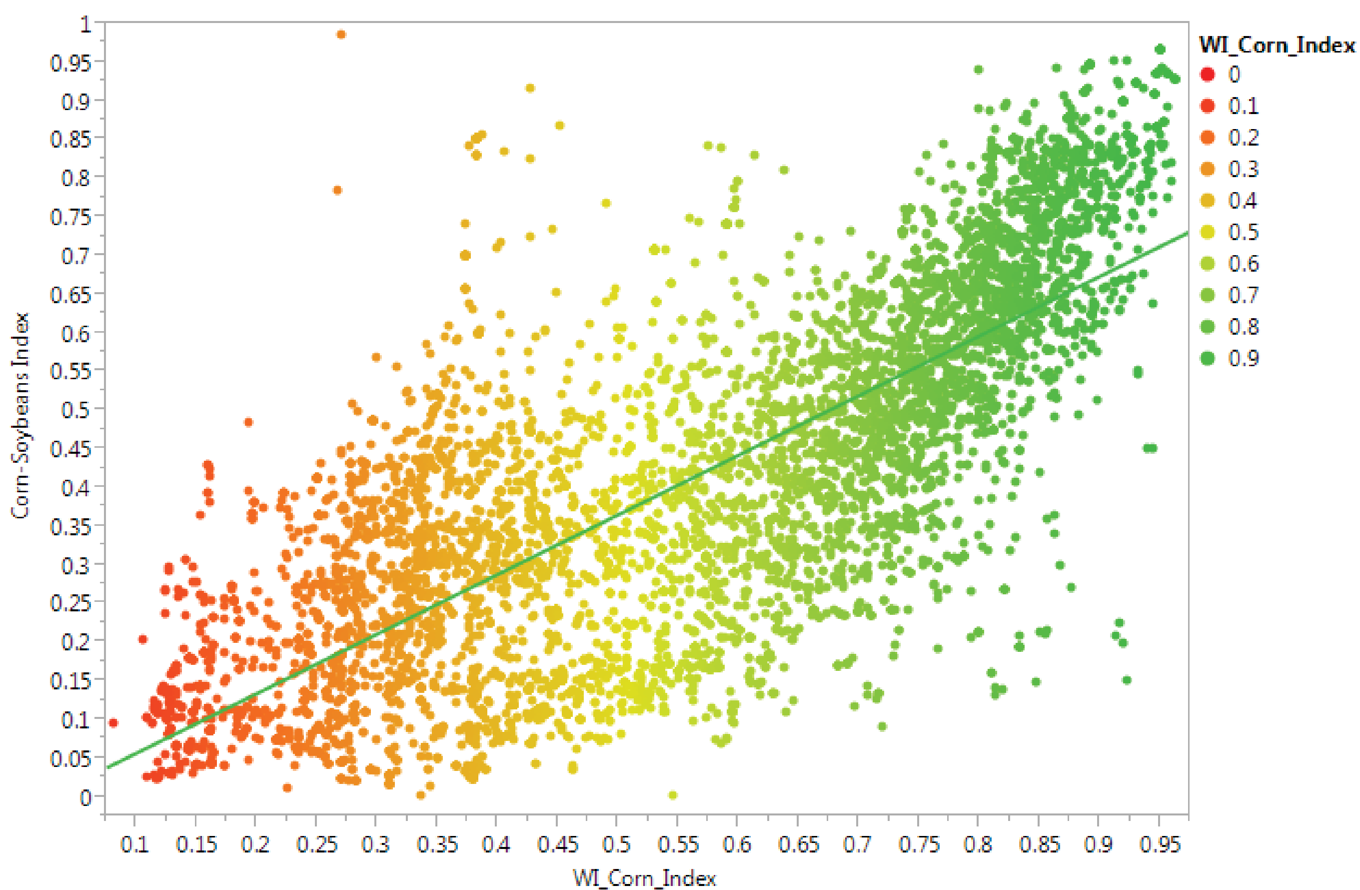


Figure 10. Comparison of the National Crop Index and the Wisconsin model.

report from the Soil Reports tab in Web Soil Survey. Onsite investigation may be needed to validate these interpretations and to confirm the identity of the soil on a given site. See Fig. 10 for a comparison of the National Crop Index and the Wisconsin model.

MODEL BREAKDOWN

Organic Matter

This is the amount, by weight, of decomposed plant and animal residue expressed as a weight percentage of the less than 2 mm soil material. Fig. 11 shows a suitability rule for organic matter.

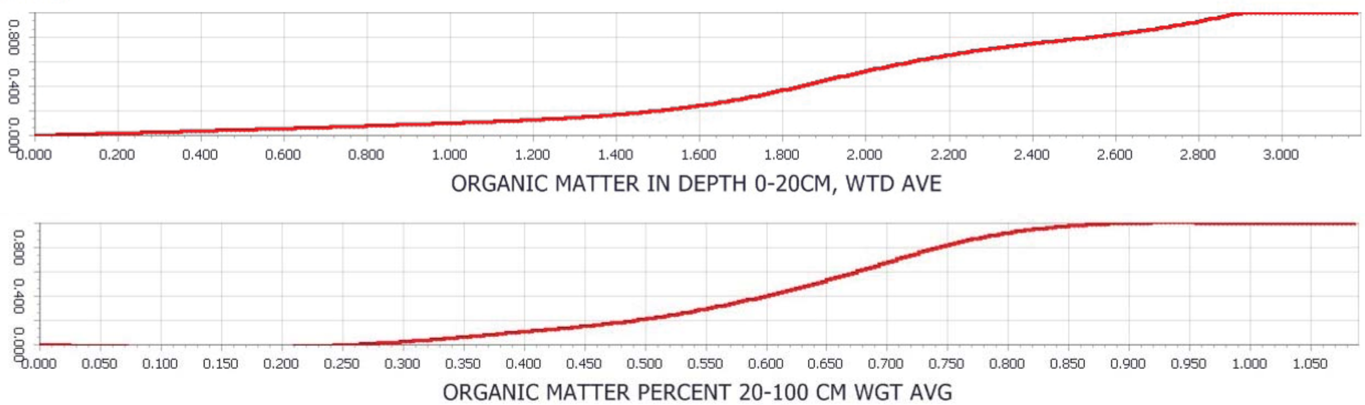


Figure 11. These two separate evaluations use weighted averages for organic matter from 0 cm to 20 cm and 20 cm to 100 cm. Then, OM 0-20 is multiplied by a weighted factor of 0.07 and OM 20-100 cm is multiplied by a weighted factor of 0.15. The hedges are null, not rated. The ratings are then summed to derive a total for OM.

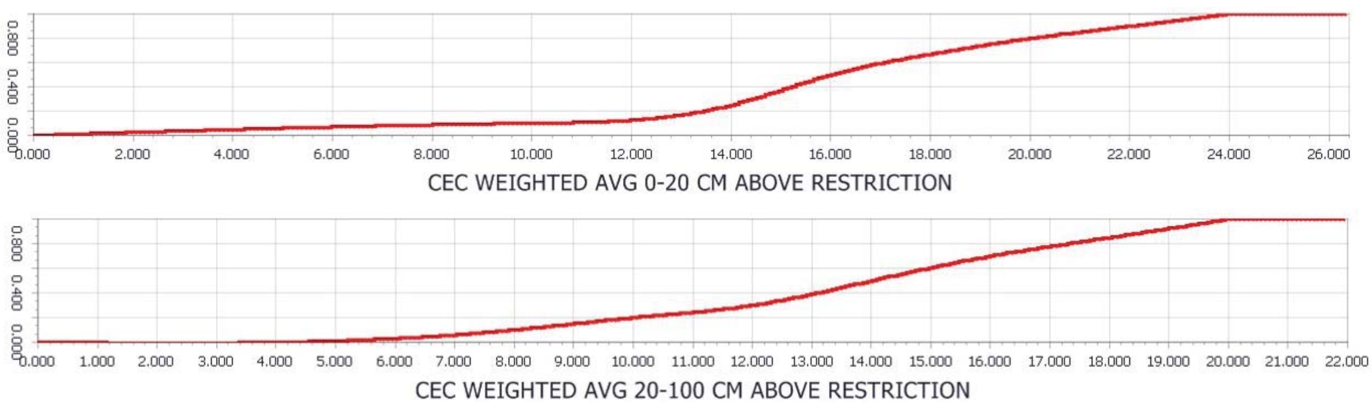


Figure 12. The CEC7 and ECEC numbers in SSURGO are stored as "raw" numbers. The CEC used to obtain the fuzzy number is a rooting depth total. CEC 0-20 centimeters uses a factor of 0.04 and CEC 20-100 centimeters uses a factor of 0.02. The two values are then summed together

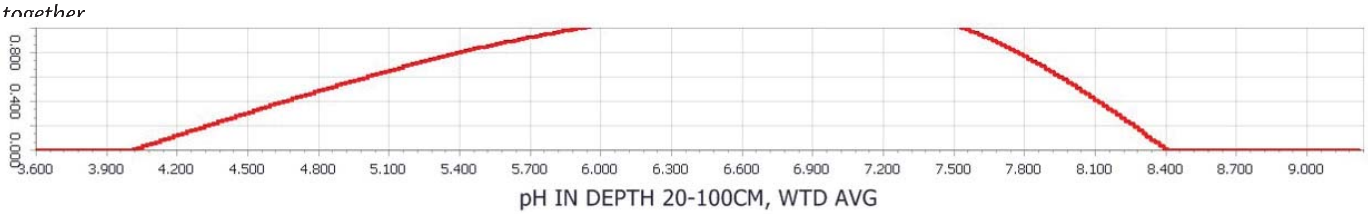


Figure 13. Weighted average pH of the 20 cm to 100 cm, or rooting depth if less than 100 cm. It uses an arbitrary curve peaking from 5.9 to 7.6. The hedge is "not null and." The rating is multiplied by a factor of 0.015.

Cation-Exchange Capacity

This is the amount of readily exchangeable cations that can be electrically adsorbed to negative charges in the soil, soil constituent, or other material, at pH 7.0, as estimated by the ammonium acetate method. It was previously reported as meq/100 g, which is equivalent to cmol+/kg. Fig. 12 shows cation-exchange capacity. CEC is a measure of the soil's ability to store and release cations, some of which are essential for plant growth. CEC is a capacity factor dependent upon the amount of soil in the rooting volume.

pH (H_2O)

This is the negative common logarithm of the hydrogen ion activity in the soil using the 1:1 soil-water ratio method. It is a numerical expression of the relative acidity or alkalinity of a soil sample. Fig. 13 shows weighted average pH.

Depth to Restrictive Feature

"Restriction kind" is the type of nearly continuous layer that has one or more physical, chemical, or thermal properties that significantly reduce the movement of water and air through the soil or that otherwise provide an unfavorable root environment. Bedrock (e.g., limestone), cemented horizons (e.g., duripan), densic material (e.g., dense till), frozen horizons or layers (e.g., permanent ground ice), and horizontally oriented, human-manufactured materials (e.g., concrete) are examples of subsurface layers that are kinds of restrictions. Fig. 14 shows depth to first restriction below organic layer.

Saturated Hydraulic Conductivity (Ksat)

This is the ease with which pores of a saturated soil transmit water. Formally, it is the proportionality coefficient that expresses the relationship of the rate of water movement to hydraulic gradient in Darcy's Law, a law that describes the rate of water movement through

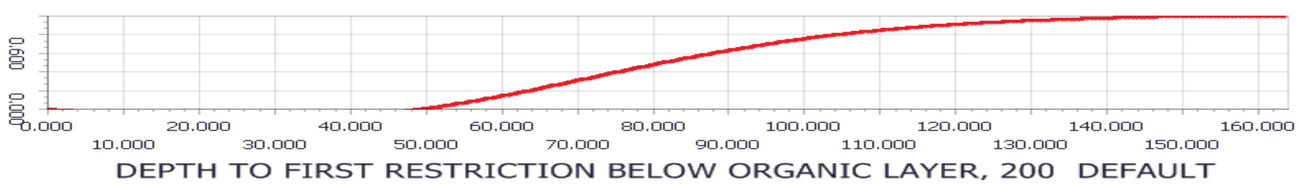


Figure 14. Evaluation is calculated by multiplying value by a factor of 0.02. This evaluation examines the depth of the component to a restrictive layer or 150 cm, whichever is less. Soils that are 150 cm or more to a dense layer, if any, score a 1. Soils that have a restrictive layer at the surface would score a zero. This uses an arbitrary curve as the design.

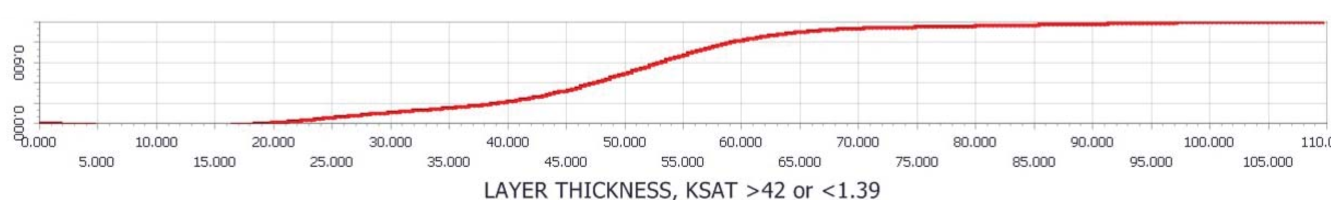


Figure 15. Evaluation is calculated by multiplying value by a factor of 0.09.

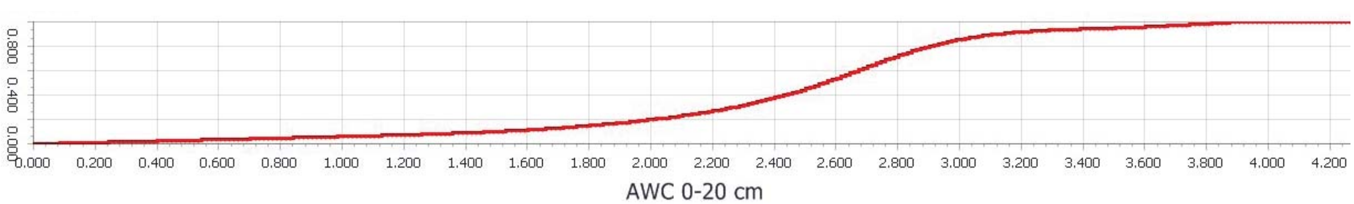


Figure 16. AWC is calculated by multiplying value by a factor of 0.11.

porous media. It is commonly abbreviated as "Ksat" and expressed as micrometers per second. To convert micrometers per second to inches per hour, multiply micrometers per second by 0.1417. Fig. 15 shows layer thickness.

Available Water Capacity

This is the amount of water that an increment of soil depth, inclusive of fragments, can store that is available to plants. AWC is expressed as a volume fraction. It is commonly estimated as the difference between the water contents at 1/10 or 1/3 bar (field capacity) and 15 bars (permanent wilting point) tension and adjusted

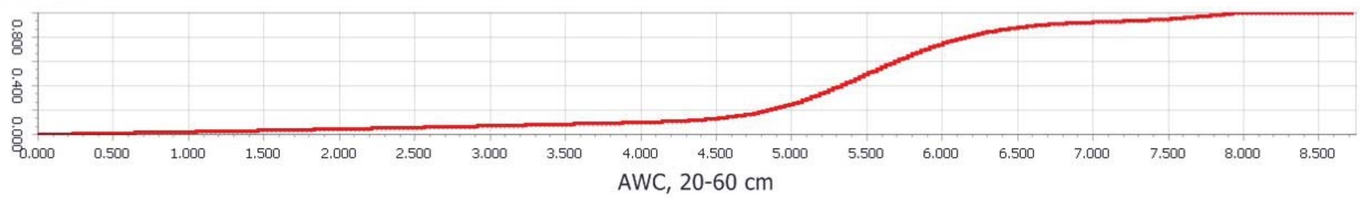


Figure 17. AWC is calculated by multiplying value by a factor of 0.14.

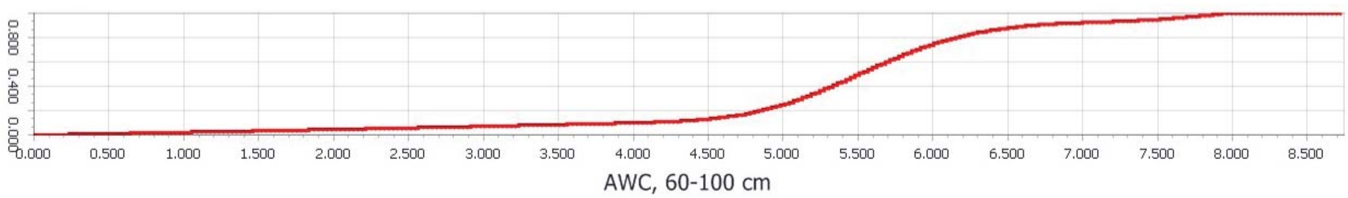


Figure 18. AWC is calculated by multiplying value by a factor of 0.06.

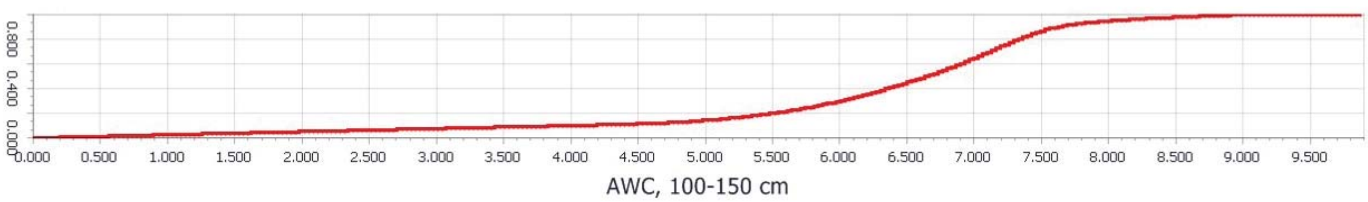


Figure 19. AWC is calculated by multiplying value by a factor of 0.03.

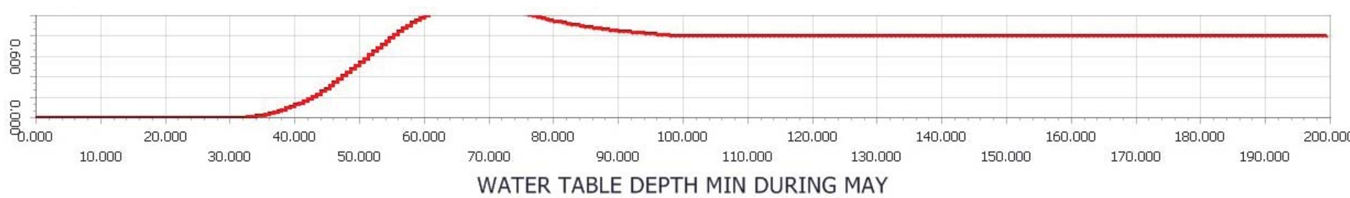


Figure 20. Evaluation is calculated by multiplying value by a factor of 0.01

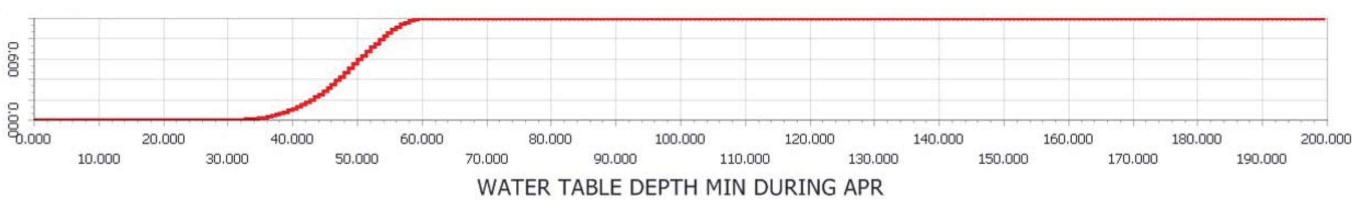


Figure 21. Evaluation is calculated by multiplying value by 0.01. Then both wetness factors are summed together.

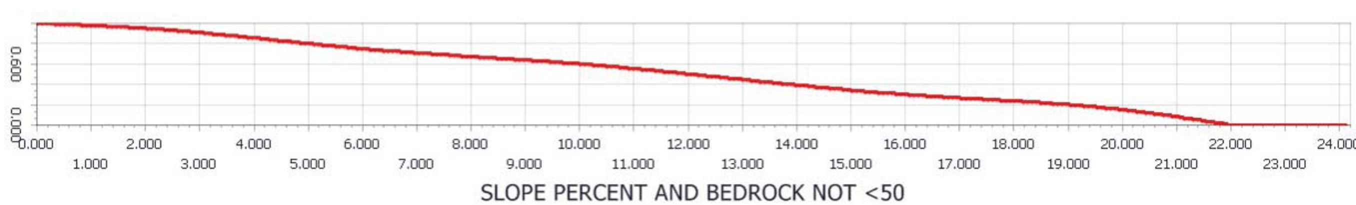


Figure 22. A soil may be a full member, partial member, or non-member of the set of soils that are too steep to grow corn. The value is multiplied by a factor of 0.2.

for salinity and fragments. Figs. 16, 17, 18, and 19 show available water capacity.

Wetness

"Soil moisture status" is the mean monthly soil water state at a specified depth. Figs. 20, and 21show water table depth.

Slope

"Slope gradient" is the difference in elevation between two points and is expressed as a percentage of the distance between those points. For example, a difference in elevation of 1 meter over a horizontal distance of 100 meters is a slope of 1% (see Fig. 22).

Flooding and Ponding

"Flooding" is the temporary covering of the soil surface by flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources. Shallow water standing or flowing that is not concentrated as local runoff during or shortly after rain or snowmelt is excluded from the definition of flooding (see Figs. 23 and 24).

Ponding is standing water in a closed depression. The water is removed only by deep percolation, transpiration, evaporation, or by a combination of these processes. Ponding of soils is classified according to depth, frequency, duration, and the beginning and ending months in which standing water is observed.

Water Balance

The model uses Thornthwaite water balance by MLRA (see Fig. 25).

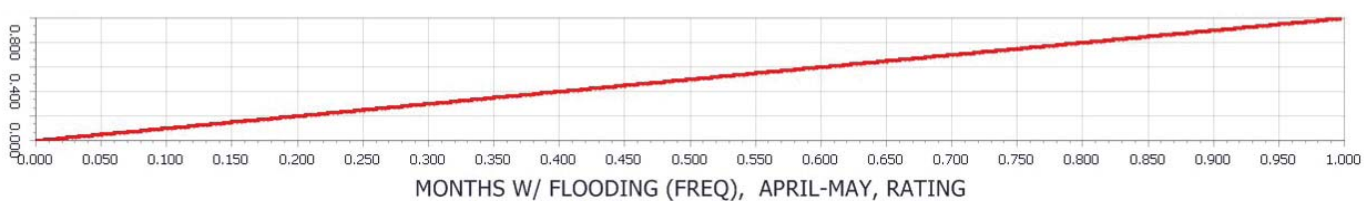


Figure 23. Flooding-ponding frequency for April-May values are multiplied by a factor of 0.02.

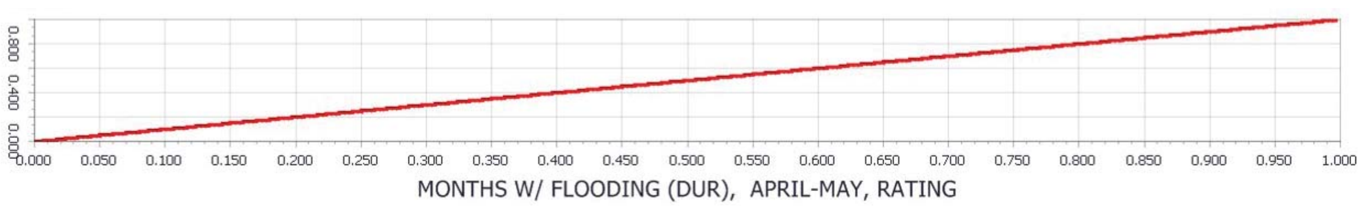


Figure 24. Flooding-ponding duration for April-May values are multiplied by a factor of 0.03. Then both factors are summed together.

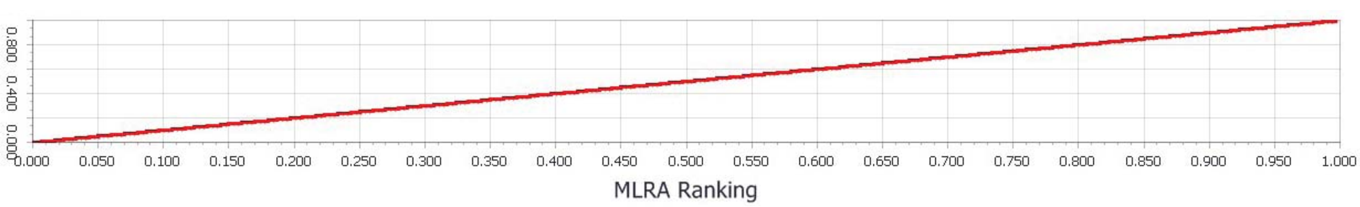
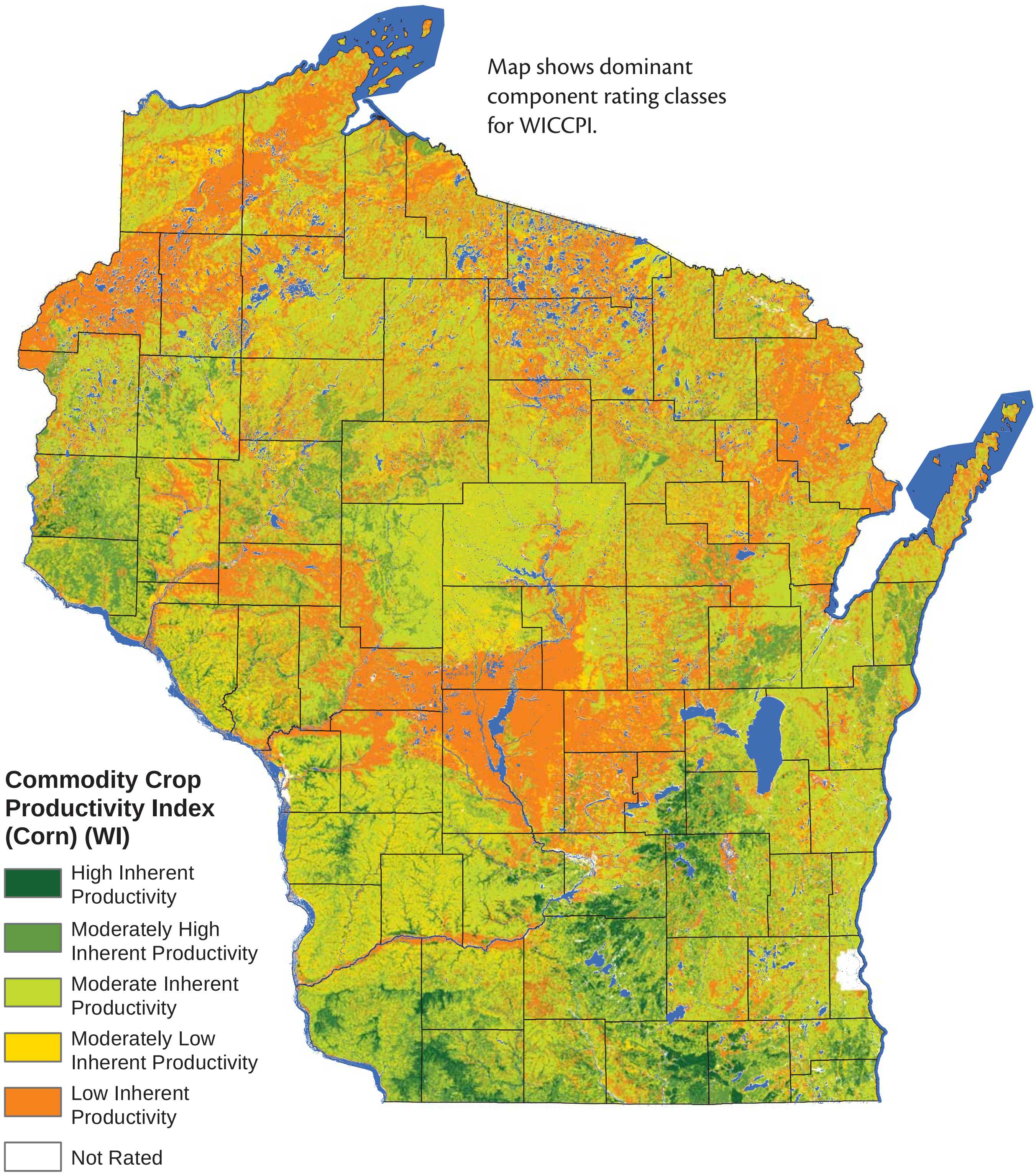
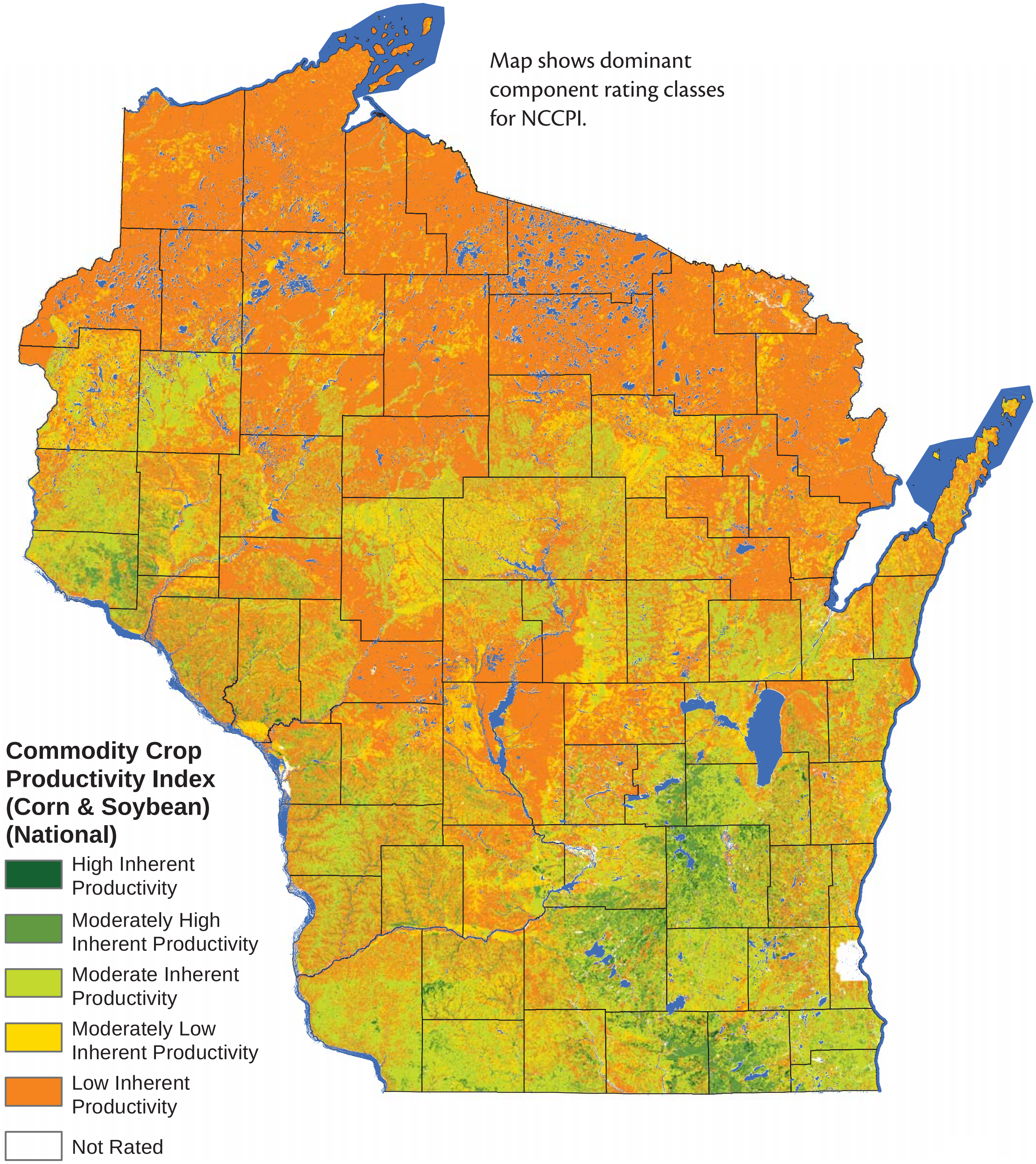


Figure 25 . The water balance factor is 0.13. The graph is arbitrary linear. The model uses Thornthwaite water balance by MLRA.

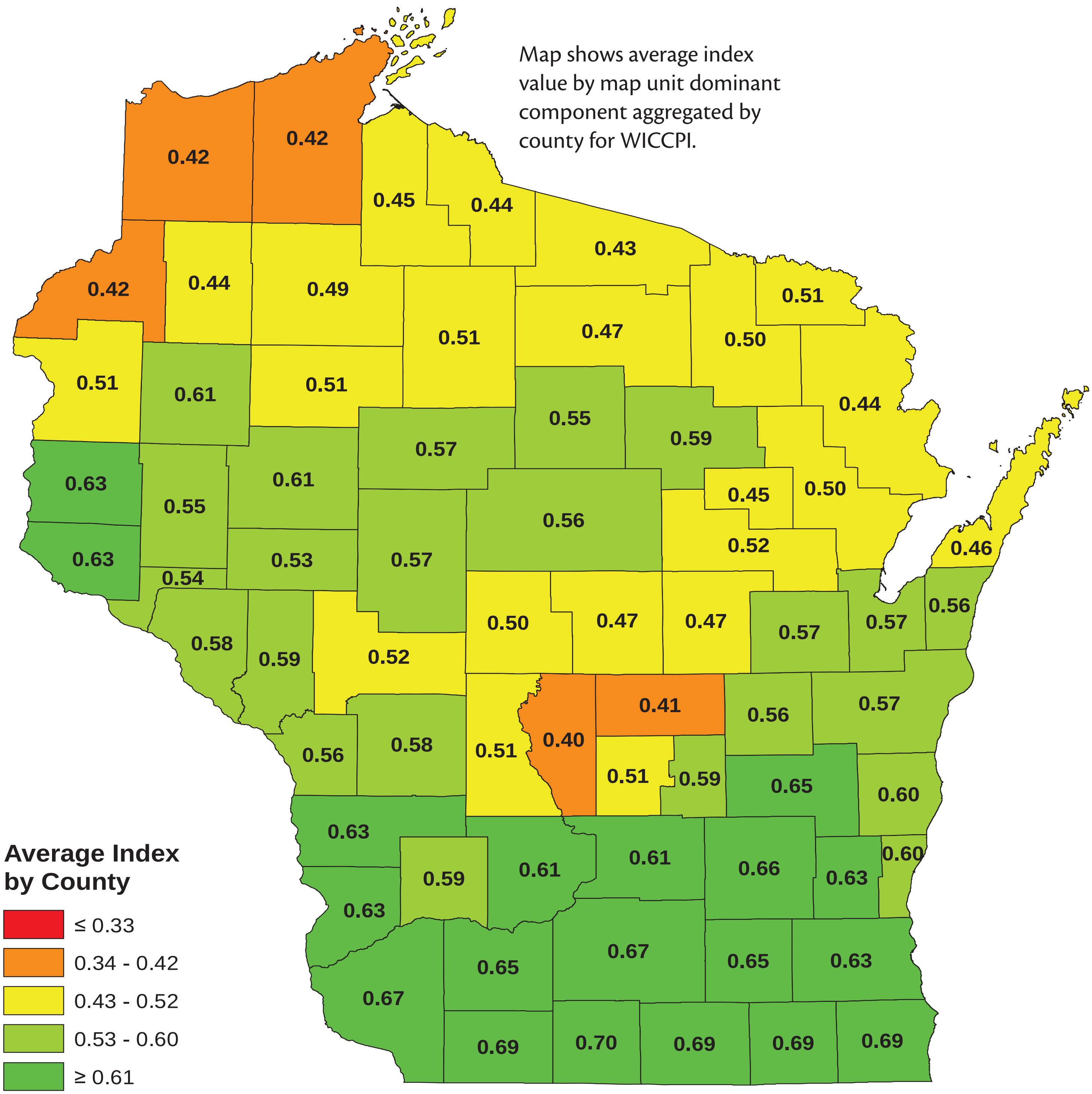
Wisconsin Commodity Crop Productivity Index (WICCPI) for Corn



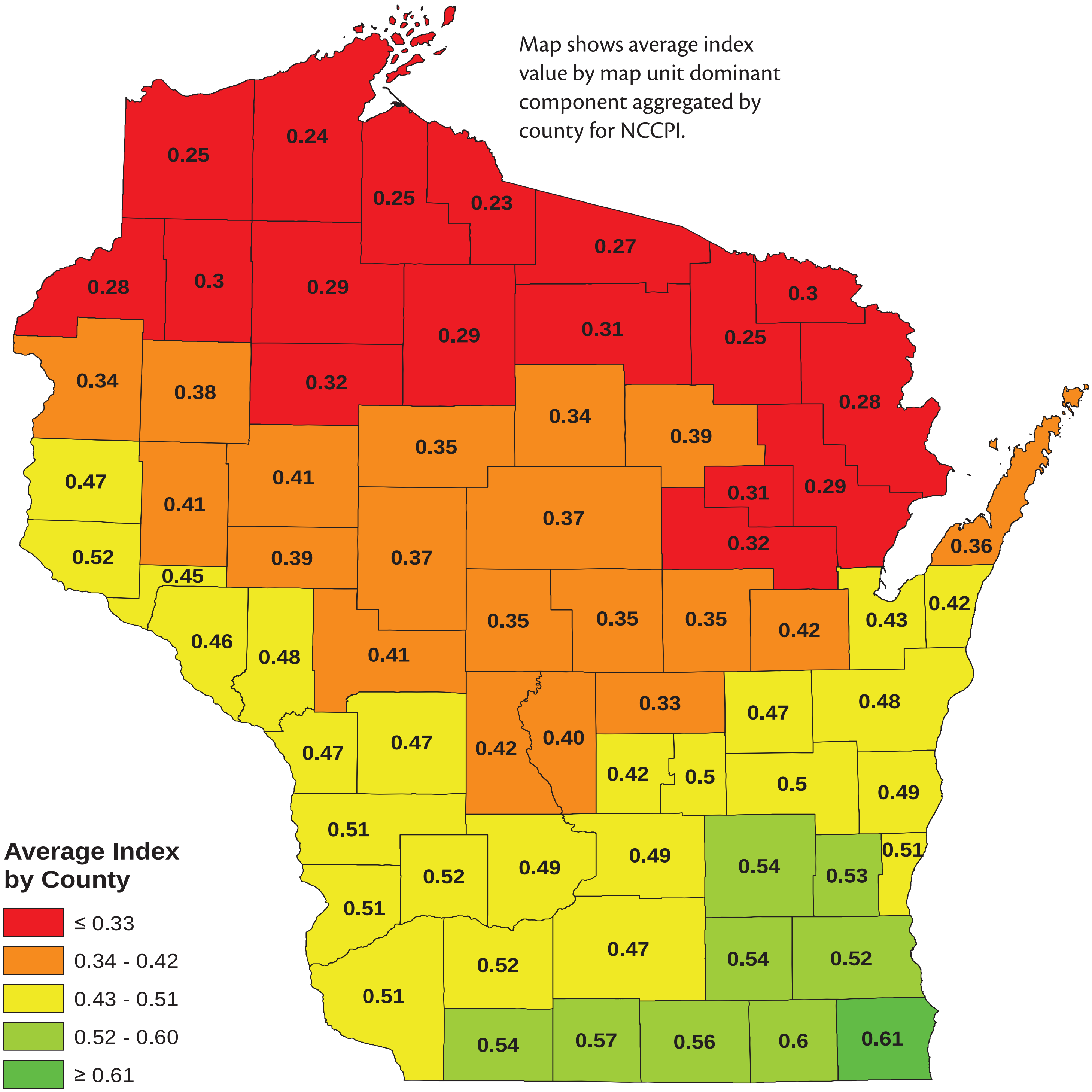
National Commodity Crop Productivity Index (NCCPI) for Corn and Soybean



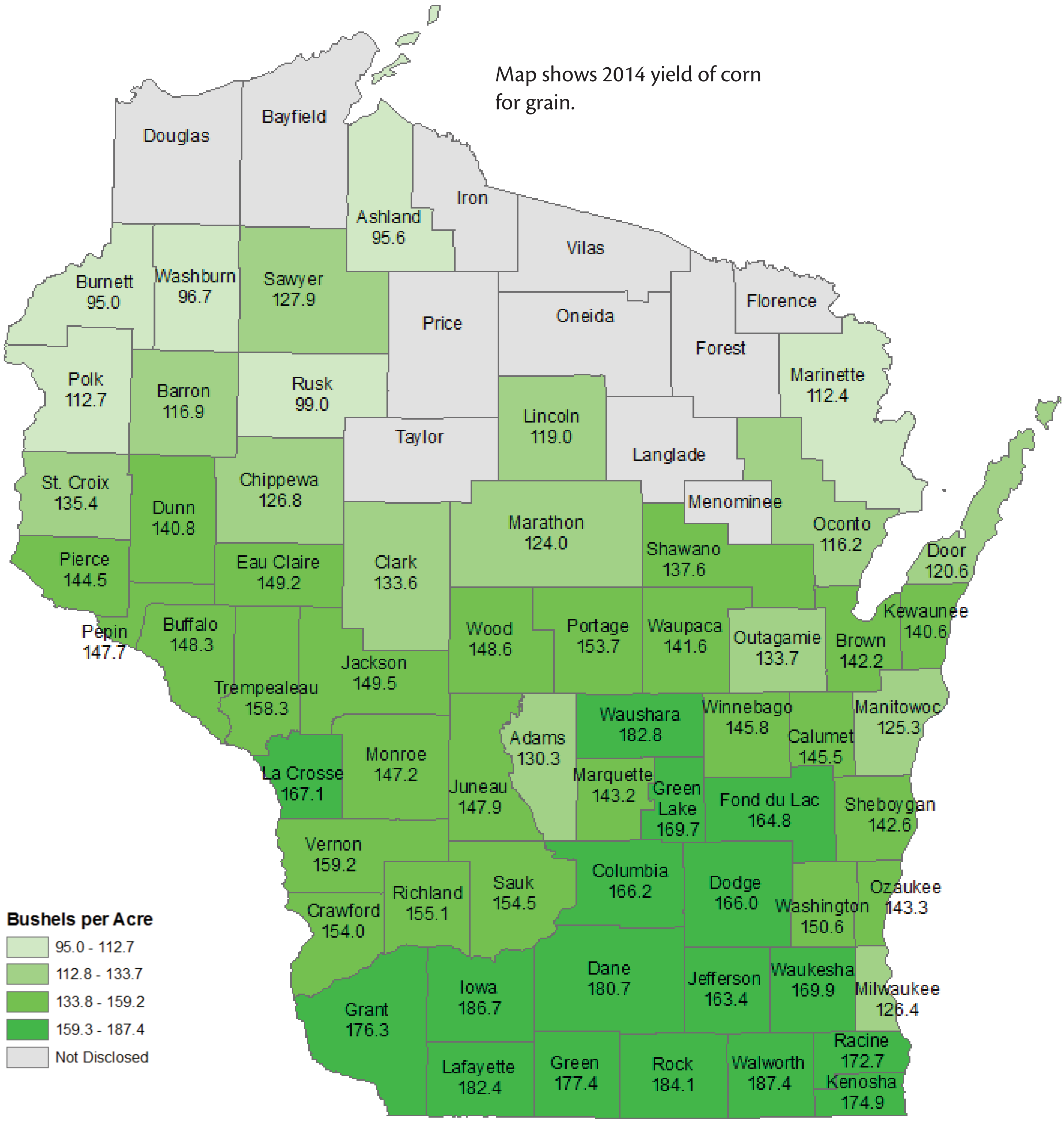
Wisconsin Commodity Crop Productivity Index (WICCPI) for Corn and Soybean



National Commodity Crop Productivity Index (NCCPI) for Corn and Soybean

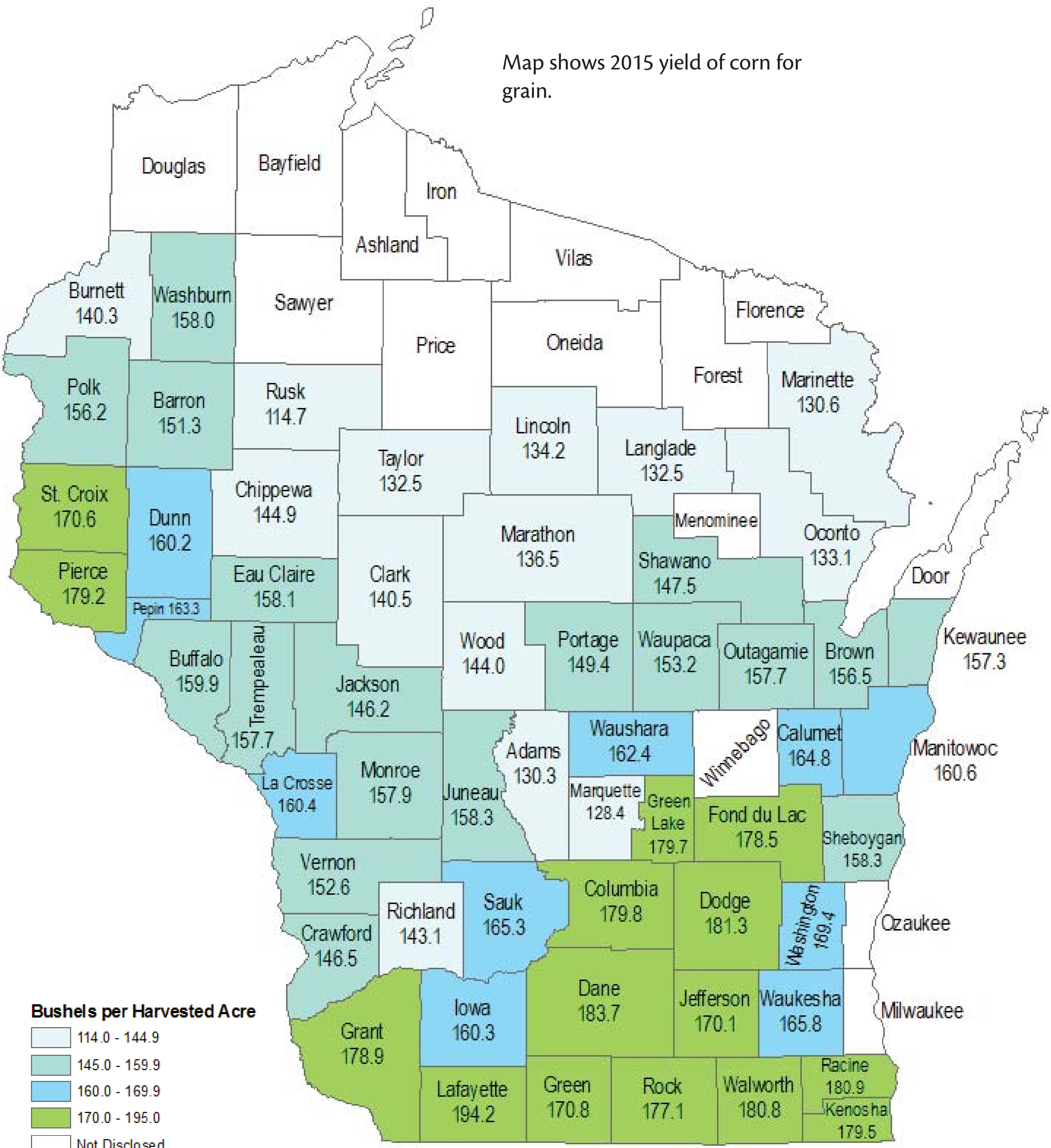


Wisconsin Ag News
2014 Corn Yield, County Estimates



Map courtesy of USDA National Agriculture Statistics Service

Wisconsin Ag News
2015 Corn Yield, County Estimates



Map courtesy of USDA National Agriculture Statistics Service

SUMMARY

- Crop production interpretation produces consistent yield index.
- Actual yield data can be used to convert the index values to yield estimates.
- Productivity index can be used to set more equitable soil rental rates.
- Local interpretations developed based on State criteria and discussions with partners can more effectively meet local needs and objectives.
- National interpretations, because of their wide scope, may not reflect specific local conditions and circumstances.

REFERENCES

Dobos, R.R., H.R. Sinclair, Jr., and K.W. Hipple. 2008. User guide for the National Commodity Crop Productivity Index (NCCPI), Version 1.0. USDA-NRCS National Soil Survey Center.

Huddleston, J.H. 1984. Development and use of soil productivity ratings in the United State. Geoderma 32:297–317.

Palmer, W.C., and A.V. Havens. 1958. A graphical technique for determining evapotranspiration by the Thornthwaite method. Monthly Weather Review, April, pp.123-128.

Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service, USDA Handbook 18.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geographic Review 38:55-94.

USDA Natural Resources Conservation Service. 1993. Soil survey manual. Soil Survey Staff, U.S. Dep. Agric. Handbook 18.

USDA Natural Resources Conservation Service. 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Survey Staff, USDA Handbook. 496.

USDA Natural Resources Conservation Service. 2016. NRCS soil interpretations. Chapter 19: Introducing interpretations . Soil Survey Staff.

USDA National Agricultural Statistics Service. 2014 corn county estimates. https://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/County_Estimates/2015/WI_CtyEst_Corn_13-14.pdf (Accessed 29 Apr. 2016.)

USDA National Agricultural Statistics Service. 2015 corn county estimates. https://www.nass.usda.gov/Statistics_by_State/Wisconsin/Publications/County_Estimates/2016/WI_CtyEst_Corn_14-15.pdf (Accessed 29 Apr. 2016.)