Site suitability for full season and double-cropped corn in Virginia

Abstract

A spatially referenced site suitability analysis was performed for full season and double-cropped corn (*Zea mays* L.) in Virginia using weighted abiotic factors Input data included gridded monthly climate data (Daly et al., 1994), National Elevation Data (NED), National Land Cover Data (NLCD), and the Virginia State Soil Geographic (STATSGO) database. Additional grids were derived from these sources including slope, aspect, Thornthwaite potential evapotranspiration (PET), and PET minus precipitation (PET-P). Maps were generated to characterize the overall suitability for corn production for individual and combined components. The length of the growing season is a limiting factor for late planted corn in the mountainous region of Virginia. PET and PET-P are used to identify areas of the state having a lower average moisture deficit during the silking months for double-cropped corn compared to full-season corn. The findings of the site suitability are in general agreement with the experiences of researchers and producers in Virginia.

Scoring method

Component and overall suitability maps were either classified on a scale of 0 to 4 or 1 to 4, depending on the specific component. Components that required a classification with a constraint (a limiting factor such as growing season length) used the 0-4 scale, where 0 indicates unsuitable conditions. If all values for a component were at least marginal, the 1 to 4 scale was used. For both situations, a classification value of 4 indicates excellent or highly suitable conditions, 3 = good or suitable conditions, 2 = satisfactory or somewhat suitable, 1 = marginal or poor suitability, and 0 = unsuitable. Individual component suitability maps were determined for soil (weighted pH, drainage, and texture values), growing season length (growing degree-days, frost-free period), and moisture deficit/surplus (weighted PET-P for silking months), landscape topography (slope, aspect), and land cover. Overall suitability was determined using a combined measurement of all individual components.

Figure 5. Reference map for latitude and longitude in Virginia.

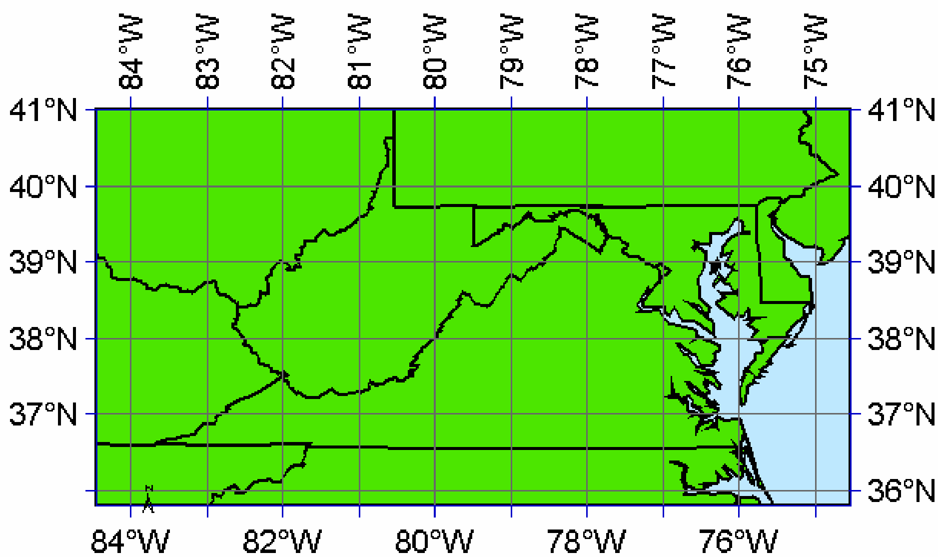


Table 12. Factors and weighting used in site suitability analysis for full season and double cropped corn.

Component	Full season corn	Double cropped corn
DD accumulation	Apr – Oct: Class (excellent, good, satisfactory, marginal, unacceptable)	Jun – Nov: Class (excellent, good, satisfactory, marginal, unacceptable)
Length of growing season	Last frost date – first frost date: Class (excellent, good, satisfactory, marginal, unacceptable)	Last frost date – first frost date - 50: Class (excellent, good, satisfactory, marginal, unacceptable)
Growing season class	(Frost Free Class + Degree Day Class) / 2	(Frost Free Class + Degree Day Class) / 2
PET silking months only	0.1Jun+0.6Jul+0.3Aug	0.3Jul+0.5Aug+0.2Sept
PET classification	Class (excellent, good, satisfactory, marginal)	Class (excellent, good, satisfactory, marginal)
STATSGO – Drainage	Class (excellent, good, satisfactory, marginal, unacceptable)	Class (excellent, good, satisfactory, marginal, unacceptable)
STATSGO – Texture	Class (excellent, good, satisfactory, marginal, unacceptable)	Class (excellent, good, satisfactory, marginal, unacceptable)
Combined Soils	0.5 (Drainage) + 0.5 (Texture)	0.5 (Drainage) + 0.5 (Texture)
Slope (Percent)	Class (excellent, good, satisfactory, marginal, unacceptable)	Class (excellent, good, satisfactory, marginal, unacceptable)
Aspect	Class (excellent, good, satisfactory, marginal)	Class (excellent, good, satisfactory, marginal)
Topography	(Slope_class + Aspect_class) / 2	(Slope_class + Aspect_class) / 2
Overall Suitability	0.3 Soil + 0.3 PET-P + 0.1 Topo + 0.3 Season	0.3 Soil + 0.3 PET-P + 0.1 Topo + 0.3 Season

Planting and Harvest dates

The values used for harvesting dates for wheat and barley were obtained from the USDA National Agricultural Statistics Service. For full season corn, planting begins April 5, is most active from Apr 20 - May 20, and ends on June 5. Corn for silage begins

April 5, is most active from April 20 to May 25, and ends on June 10. Barley is typically harvested beginning May 30, most actively from Jun 10 to Jun 25, and ending July 15. Wheat begins June 5, is most active Jun 20 - Jul 15, and ends July 25.

The Virginia Cooperative Extension Agronomy Guide, Part I: Crop Description (Brann, 2001) recommends that full-season corn be planted one week before to one week after the average date of the last killing frost in the spring. “Double-cropped corn can be planted up to July 1. Harvest dates for silage range from August 15 to October 1. For grain, harvest dates are September 1 to November 1.

Table 13. Usual Planting and Harvesting Dates for Barley, Corn, and Wheat in Virginia (USDA NASS).

Crop	**Usual Planting Dates**			**Usual Harvesting Dates**		
	Begin	**Most Active**	**End**	**Begin**	**Most Active**	**End**
Barley, Fall	Sep 10	Oct 5 - Oct 30	Nov 25	May 30	Jun 10 - Jun 25	Jul 15
Corn, for Grain	Apr 5	Apr 20 - May 20	Jun 5	Aug 25	Sep 5 - Oct 25	Nov 20
Corn, for Silage	Apr 5	Apr 20 - May 25	Jun 10	Aug 5	Aug 30 - Oct 1	Oct 20
Wheat, Winter	Sep 25	Oct 20 - Nov 15	Nov 30	Jun 5	Jun 20 - Jul 15	Jul 25

Growing Season Length

The growing season length was heavily weighted variable in the component summaries. Full season corn growing season length component was classified on a scale of 0-4 where 4 =excellent, 3 =good, 2 = satisfactory, 1 = marginal, 0 = unacceptable. The same classification was used for double cropped corn suitability, however, the growing season length required an adjustment for small grain maturation in the spring. The

PRISM degree day layers provide gridded monthly means and the accumulated degree-days were calculated as:

Full Season Corn DD =

April + May + June + July + August + September + October

Double cropped corn DD =

June + July + August + September + October + November

Table 14. Degree-day (base 50 F) suitability classification for full season corn.

Values (range)		Classification	Description
Minimum	**Maximum**		
1794 – 2000		0	Unsuitabile
2001 – 2450		1	Marginal
2451 – 2900		2	Satisfactory
2901 – 3200		3	Good
3201 – 4400		4	Excellent

Table 15. Degree-day (base 50) suitability classification for double-cropped corn.

Values (range)		Classification	Description
Minimum	**Maximum**		
1594 – 2000		0	Unsuitable
2001 – 2450		1	Marginal
2451 – 2900		2	Satisfactory
2901 – 3200		3	Good
3201 – 3816		4	Excellent

Table 16. Frost free days (mean) suitability classification for full season and double cropped corn. The number of frost free days is derived from the mean first frost date minus the mean last frost date.

Values (range)		Classification	Description
Minimum	Maximum		
<100		0	Unsuitable
101 - 115		1	Marginal
116 – 130		2	Satisfactory
131 – 145		3	Good
146 – 250		4	Excellent

Corn Modified Growing Degree Day (MGDD) model

The most common method for measuring plant development is the growing-degree-day (GDD) index, which is the average daily temperature minus the base developmental threshold. For corn, this base threshold is widely used as 10 °C (50 °F), though it is known that the developmental rate of the plant changes depending on the developmental stage. The model presented here uses the Modified Growing Degree-Day (MGDD) method (REF Coelho and Dale, 1980). The MGDD is similar in form to the GDD method, Both assume a linear development rate through all developmental stages of the plant, however the MGDD model treats minimum and maximum temperature thresholds separately. The MGDD model uses a horizontal cutoff on both the upper and lower temperature thresholds. For example, if the maximum daily temperature exceeds the maximum temperature threshold (30°C) then the daily temperature maximum is set to 30°C.

$$MGDD = \sum \{ [(T_{min} + T_{max}) / 2] - 10\ °C \}$$

where:

T_{min} = minimum daily temperature, T_{min} (< 10) = 10 °C (50 °F)

T_{max} = maximum daily temperature, T_{max} (> 30) = 30 °C (86 °F)

In this analysis, corn was considered to be of a 95 – 105 day relative maturity. The estimated accumulation from planting to harvest is approximately 2450 degree-days (°F), the number used in the degree-day classification.

Table 17. Approximate accumulated MGDD units for corn development (95 -105 day relative maturity).

	Developmental stage	**F**	**C**
0	Planting	0	0
1	Emergence	125	51.7
2	V6	470	243.3
3	V10	645	340.6
4	V12	815	435.0
5	V16	985	530.8
6	V18	1160	626.7
7	VT	1200	648.9
8	R1 (silking)	1250	676.7
9	R2 (blister)	1450	787.8
10	R3 (milk)	1700	926.7
11	R4 (dough)	1800	982.2
12	R5 (dent)	2100	1148.9
13	R6 (physiological maturity)	2300	1260.0
14	Harvest	2450	1343.3

Using the MGDD model, the most sensitive stages of corn development can be estimated as the VT stage through the R1 stage, or 1200 degree-days (°F) up to 1450 degree-days (°F).

Potential Evapotranspiration and Potential Evapotranspiration Minus Precipitation

There are a number of different methods for calculating PET. The Thornthwaite method is suitable for PET calculations at monthly time steps, but may not perform well for daily calculations. A more suitable method for daily calculations is the Penman-Monteith method, though this also has limitations. It has been reported in the literature (FAO, 1998) that the Thornthwaite method may overestimate PET under conditions of low net radiation and low air temperatures, while the Penman-Monteith method overestimates under conditions of high net radiation and high air temperatures.

PRISM grids are given in degrees Celsius to a tenth of a degree precision, but are stored as integer grids for the purpose of efficiency. Thus, the monthly climate grids were imported from ASCII integer data to a floating point ESRI GRID and divided by a factor of ten to obtain the correct data storage type and units. All PET input factors were represented as gridded data, including the day length correction factor which was calculated using an ArcGIS Visual Basic macro which calculates the value of each cell in a 0.1 decimal degree grid (400 rows by 300 columns).

Potential evapotranspiration was calculated by the Thornthwaite (1948) method using PRISM monthly temperature and precipitation climate grids. A day length correction factor was included in PET calculations as a 0.1 degree resolution grid created as a function of latitude and day of the year (Forsythe et al, 1995). The Forsythe model was incorporated into an ArcGIS macro (VB script) to calculate the day length value for each cell in a grid from 84°W to 75°W and 36°N to 46°N (Figure 5) as a monthly estimate using the 15th day of each month to represent the entire month.

Thornthwaite potential evapotranspiration (cm/month):

$$\text{Mean monthly PET} = dl * 16 * (10 * T_a / I)^a \text{ for } T_a > 0, \text{ else } i = 0$$

where: dl = day length (hours) / 12

T_a = mean monthly temperature (Celsius)

$I = \sum (i)$

$i = (T_a / 5)^{1.514}$ for $T_a > 0$, else $i = 0$

$a = 0.049 + (0.079 * I) – (0.0000771 * I^2) + (0.000000675 * I^3)$

Table 18. Classification of full season corn PET-P (silking months).

Values (range)		Classification	Description
Minimum	**Maximum**		
-52.4	-10.0	4	Excellent
-9.9	0	3	Good
0.1	30.0	2	Fair
30.1	58.0	1	Marginal

Table 19. Classification of double cropped corn PET-P (silking months).

Values (range)		Classification	Description
Minimum	**Maximum**		
-61.2	-10.0	4	Excellent
-9.9	0	3	Good
0.1	30.0	2	Fair
30.1	49.0	1	Marginal

Photoperiod

A day length model for photoperiod (Forsythe et al., 1995) was used to generate monthly grids of hours of day length (cell size of 0.1 decimal degree). This served as input for the PET adjustment. Day length and photoperiod are at least contributing factors for many other biological phenomena, such as European corn borer diapause and flowering in sensitive plants.

Figure 6. Day length as a function of latitude.

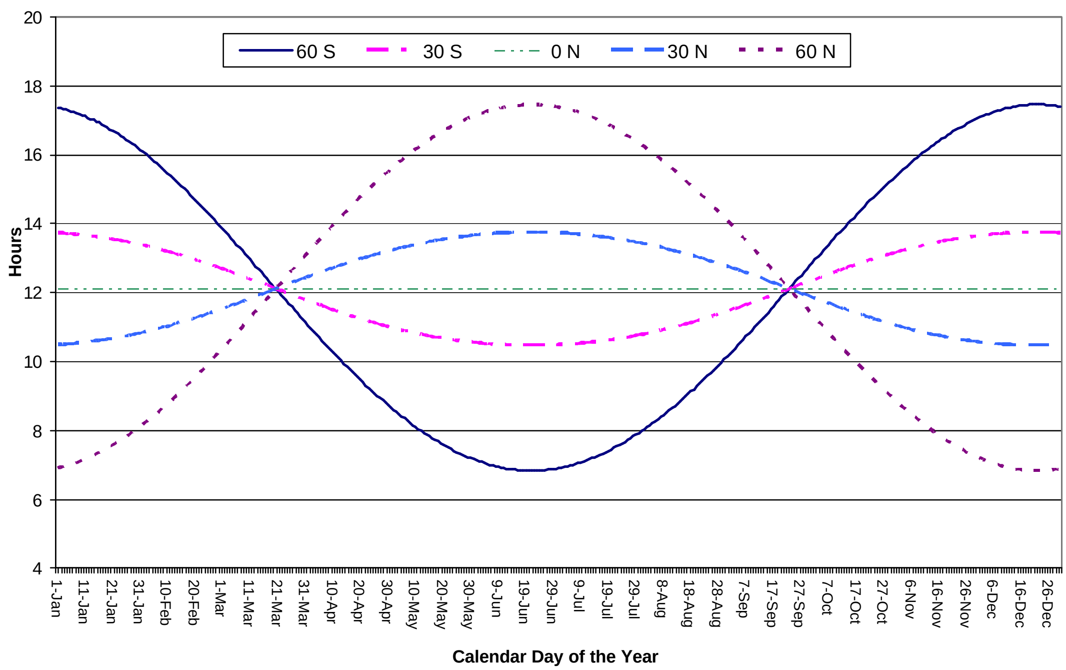
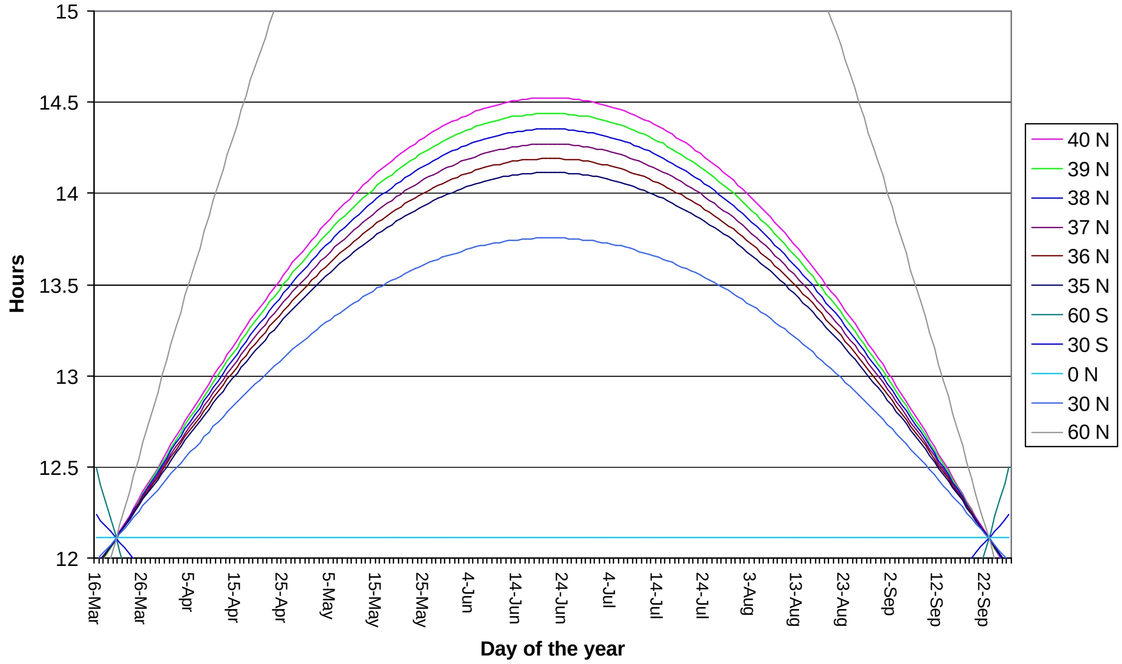


Figure 7. Day length as a function of latitude in the middle-Atlantic U.S.



Soil characteristics

The STATSGO data was used to represent the soil texture, drainage class, and average pH of soils in Virginia. STATSGO is a polygonal dataset made up of unique, spatially referenced (shape, area, and location) map units that are linked to tables of soil component data.

The VCE Agronomy Guide (Part I) recommends a pH range of 5.8 – 6.2 for field corn. A suitable range of soil drainage for corn is given as well drained to somewhat poorly drained soils. Since soil pH levels are relatively easy to manage, soil pH was not included in the analysis.

Slope and aspect

Digital elevation models for the middle-Atlantic states of Virginia, Maryland, Delaware, and North Carolina were obtained from the National Elevation Dataset (NED)

(Gesch et al., 2002) through the USGS spatial server (USGS National Map). NED is a seamless digital elevation model for the entire United States which can be easily extracted from the website interface. However, there is a limitation of 100 MB per tile that can be downloaded, so that a large selection area will result in multiple files. Fourteen tiles were needed to cover the extent of Virginia, Maryland, Delaware, and West Virginia. Data was imported to ArcGIS and checked for consistency. Next, the tiles were merged into a single file in order to represent only the state of Virginia for the site suitability analysis. In ArcGIS this can be accomplished with the ArcInfo command using the raster calculator: OutFile = merge(grid1, grid2,…, gridx).

The suitability analysis was performed in GCS North American 1983, which is also the projection for NED downloaded from the USGS website. Latitude and longitude are measured in decimal degrees, whereas elevation is in meters. In Blacksburg, one degree of latitude is 69 miles and one degree of longitude is 54 miles. These numbers reveal how geographic coordinate systems result in grids cells with unequal x- and y-lengths. This can cause serious errors in slope calculations. Therefore, the merged dataset was projected in UTM coordinates, so that all latitude, longitude, and elevation were all measured in meters (Sforza and Carstensen, 2004). Slope and aspect grids were derived using the ArcGIS Spatial Analyst Extension with a z-value of one. The slope value for each cell in the grid is given as in degrees. Aspect is given in degrees from north, proceeding in a clockwise rotation from 0 to 359 degrees.

Upon calculation of slope and aspect values from NED, the source data was determined to be of poor quality when considered as a mosaiced dataset. Therefore, the topography component (slope and aspect) were lightly weighted in the final overall suitability calculation.

Table 20. Classification of percent slope for full season and double cropped corn.

Values (range)		Classification	Description
Minimum	**Maximum**		
> 12.1		0	Unsuitable
7.6 – 12.0		1	Marginal
5.1 – 7.5		2	Satisfactory
2.6 – 5.0		3	Good
0-2.5		4	Excellent

Table 21. Classification of aspect (degrees) for full season and double cropped corn.

Values (range)		Classification	Description
Minimum	**Maximum**		
0 – 44, 316 – 359		2	Satisfactory
45 – 135, 225 – 315		3	Good
135 – 225		4	Excellent

Figure 8. Primary soil component name for Virginia from the USGS STATSGO database.

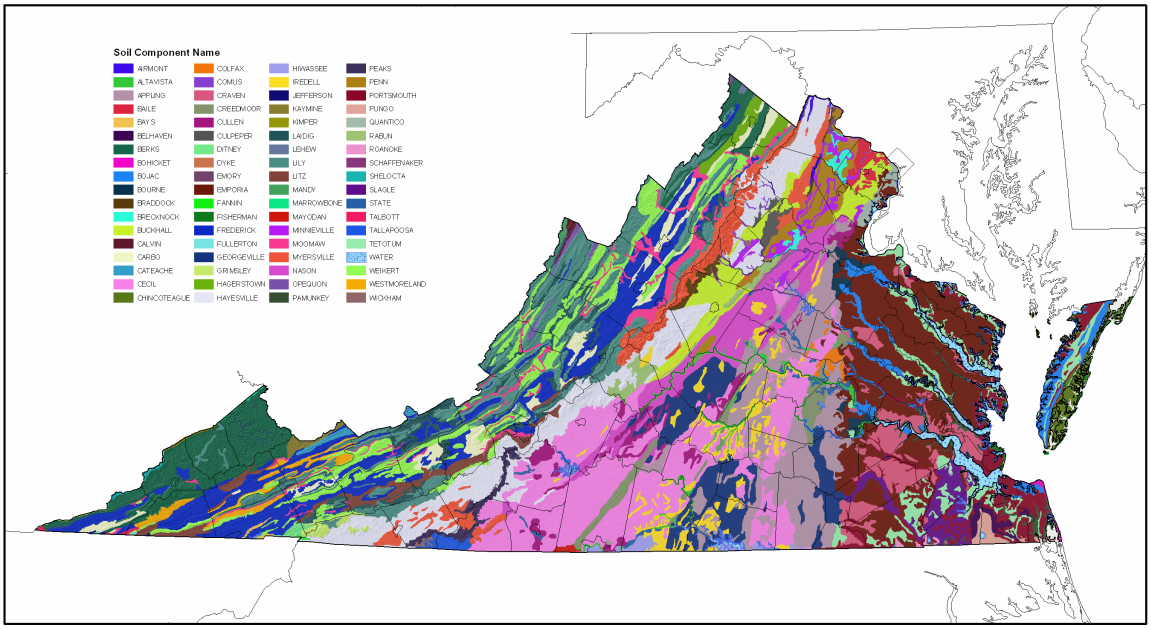


Figure 9. Surface soil texture for Virginia from the USGS STATSGO database.

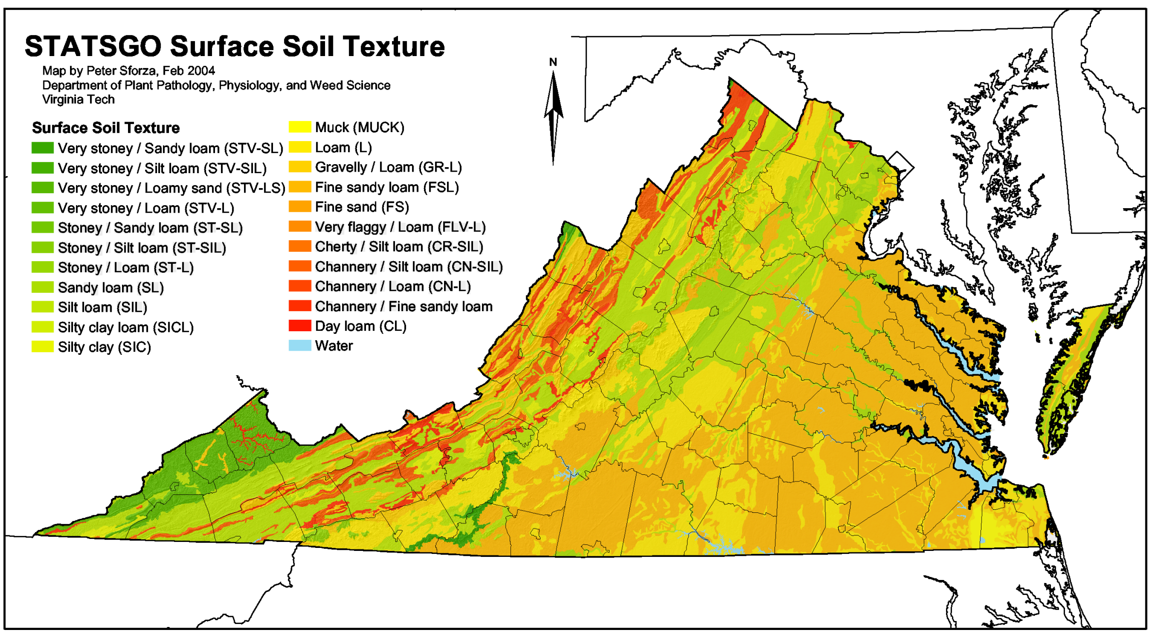


Figure 10. Soil drainage classification for Virginia from the USGS STATSGO database.

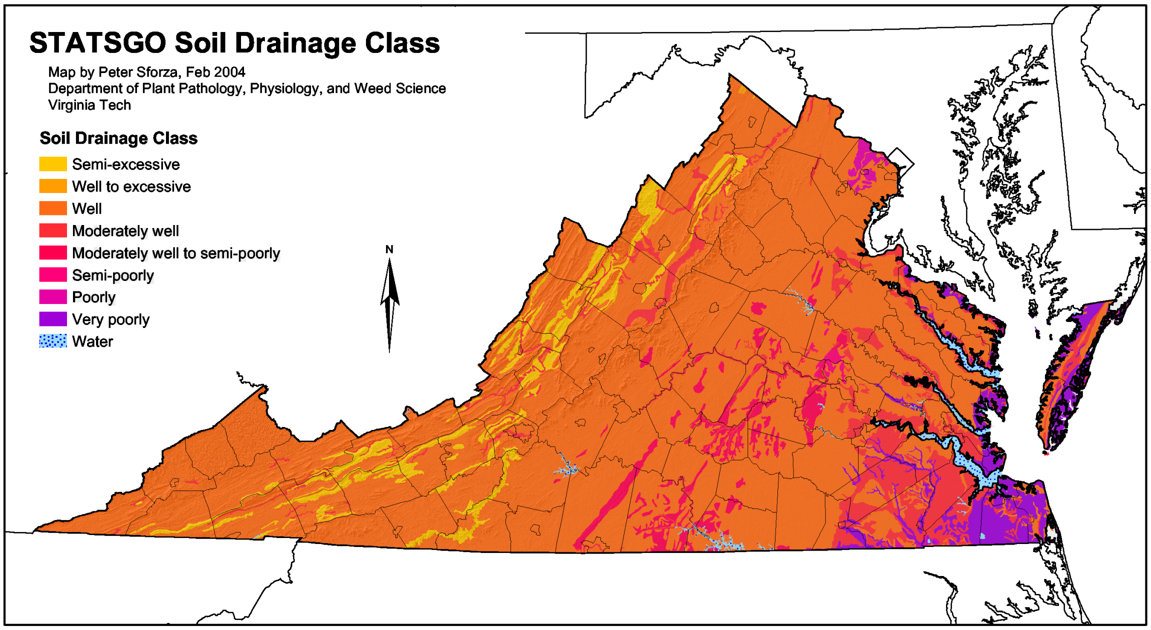


Figure 11. 30-year mean annual frost free days for Virginia, used as a proxy for full season corn.

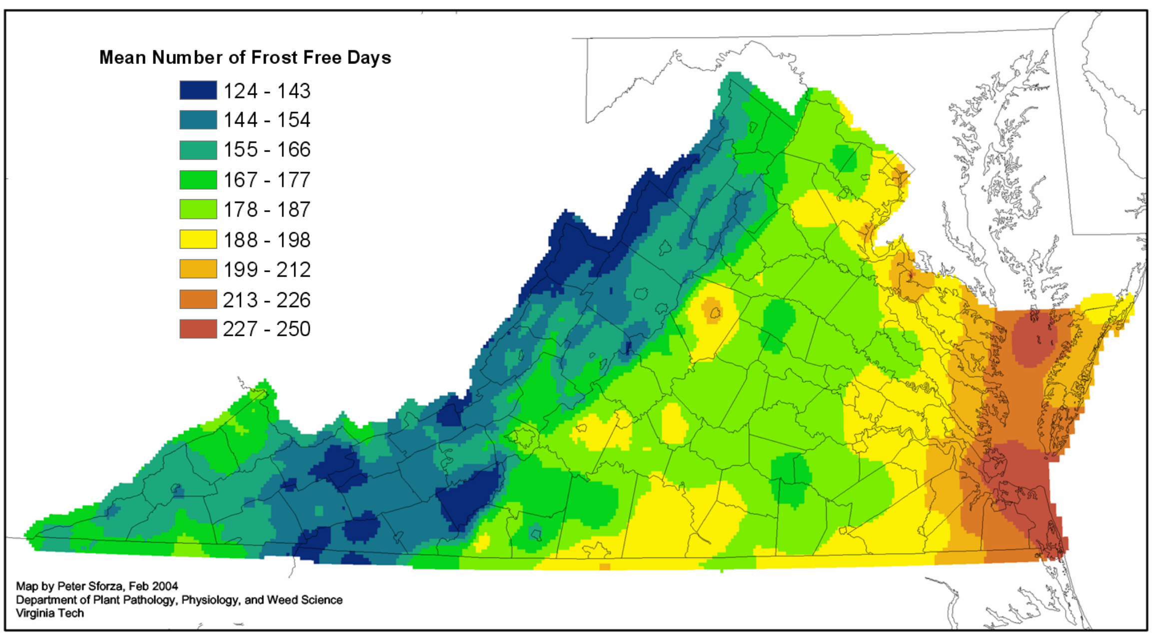


Figure 12. 30-year mean annual frost free days minus 50 for Virginia, used as a proxy for double cropped corn.

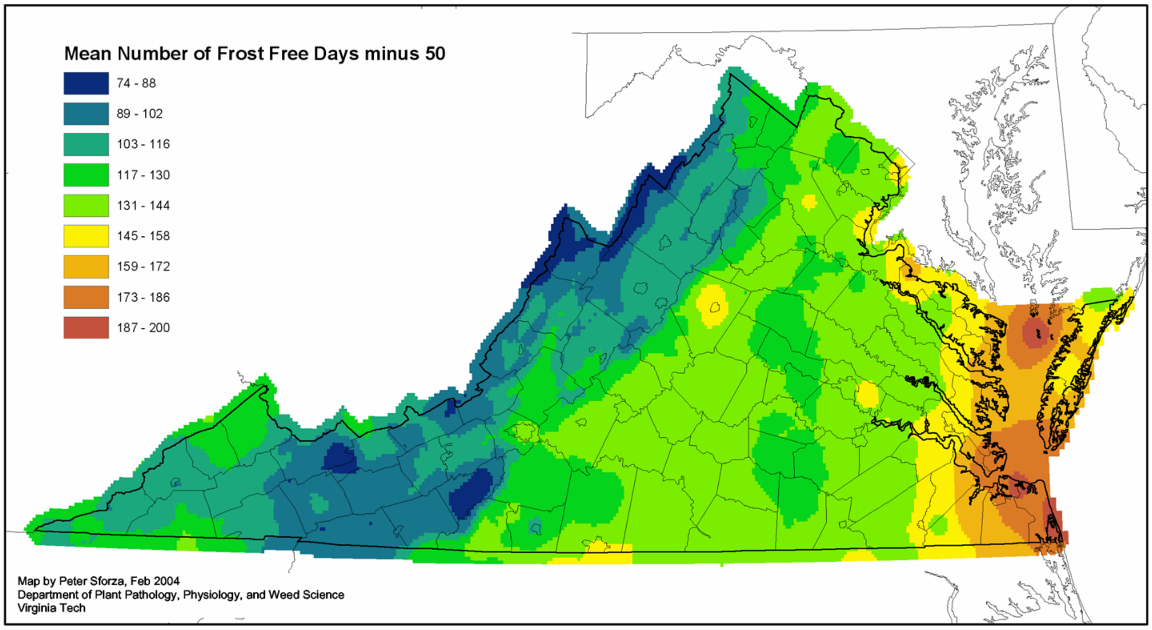


Figure 13. 30-year mean accumulated degree days from April to October (base 50°F) for Virginia, used as a proxy for full season corn.

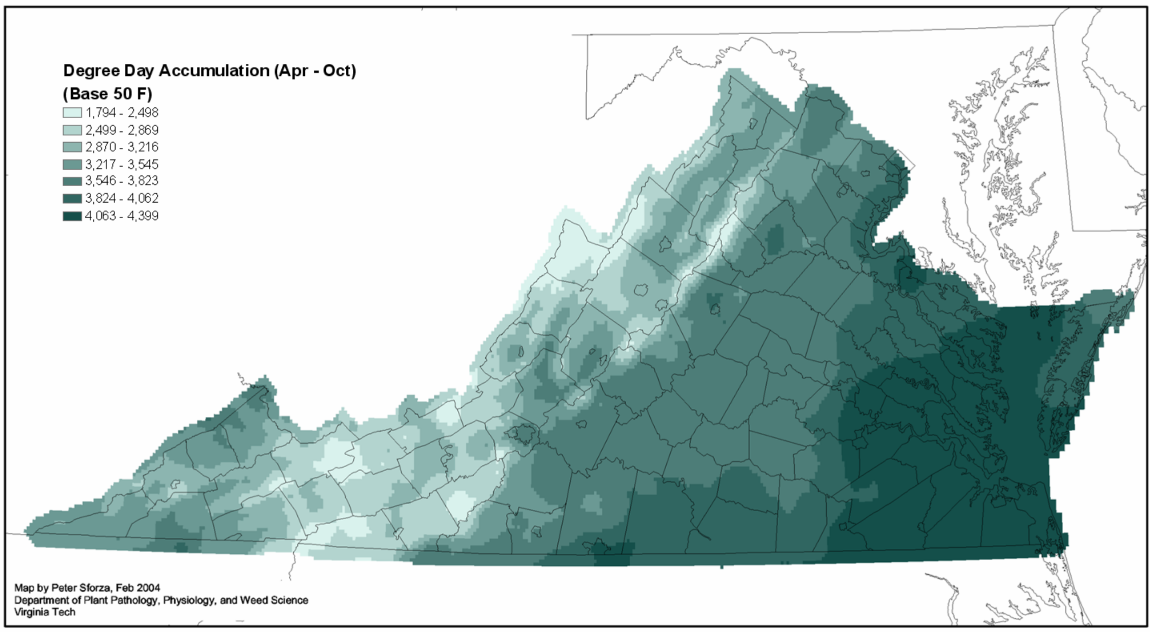


Figure 14. 30-year mean accumulated degree days from June to November (base 50°F) for Virginia, used as a proxy for double cropped corn.

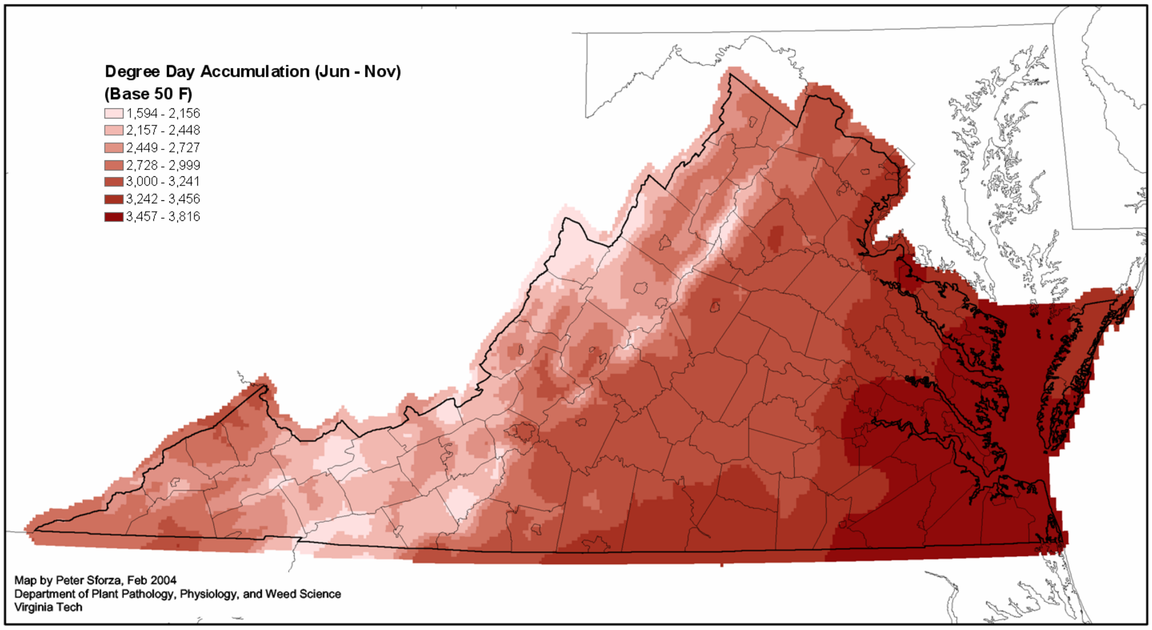


Figure 15. 30-year mean first frost date for Virginia.

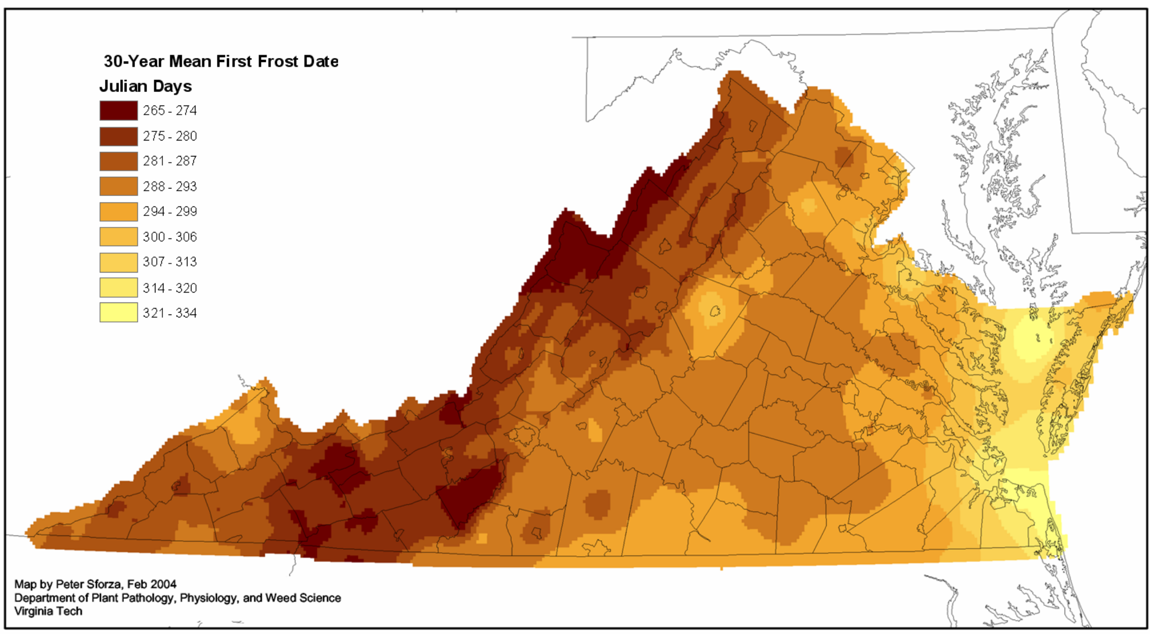


Figure 16. 30-year mean last frost date for Virginia.

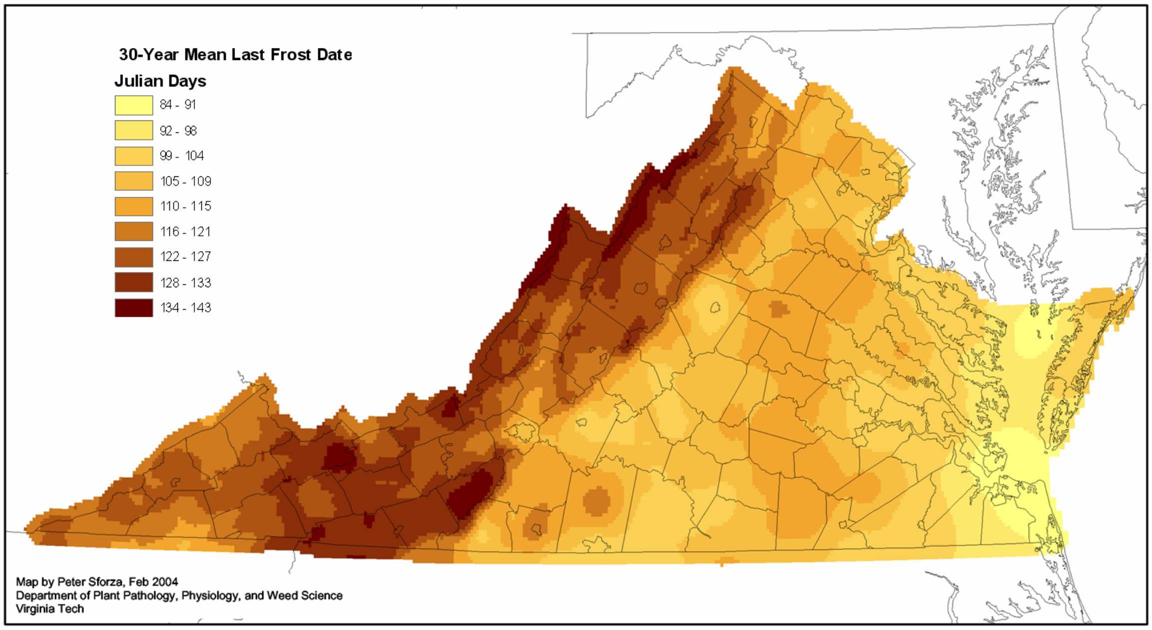


Figure 17. Percent slope calculated from the National Elevation Dataset (USGS).

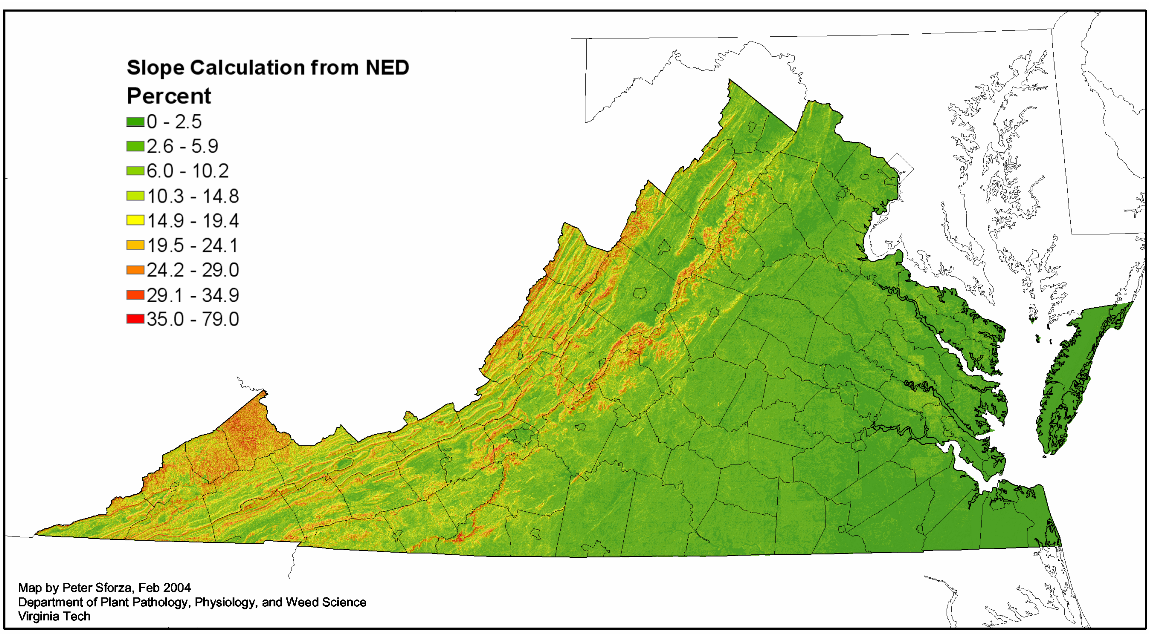


Figure 18. Aspect calculated from the National Elevation Dataset (USGS).

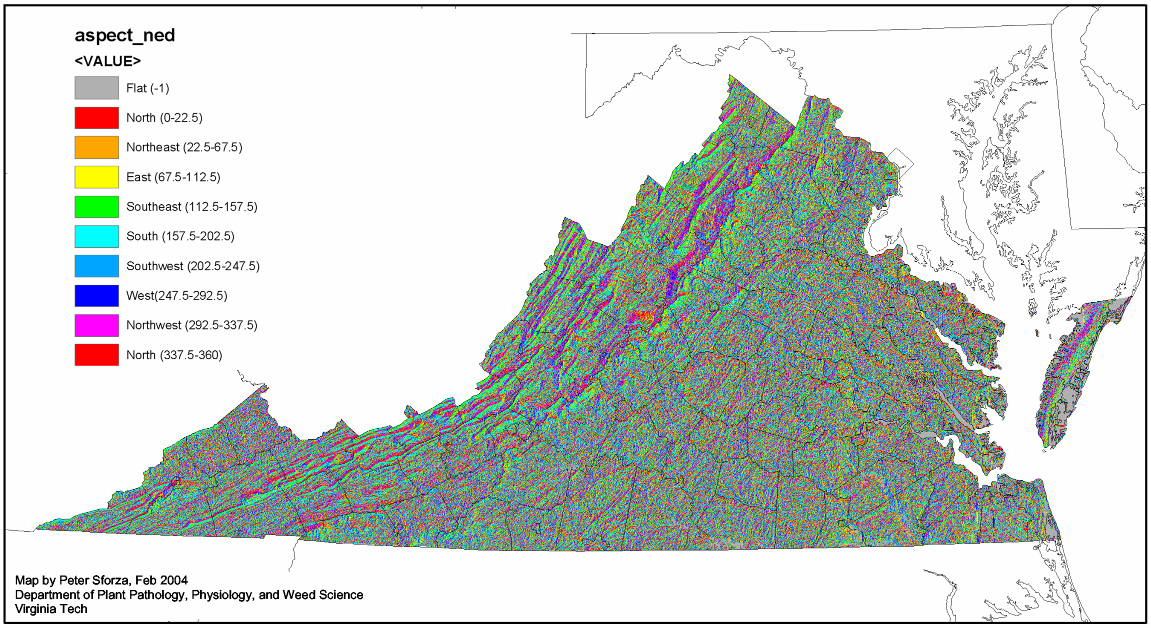
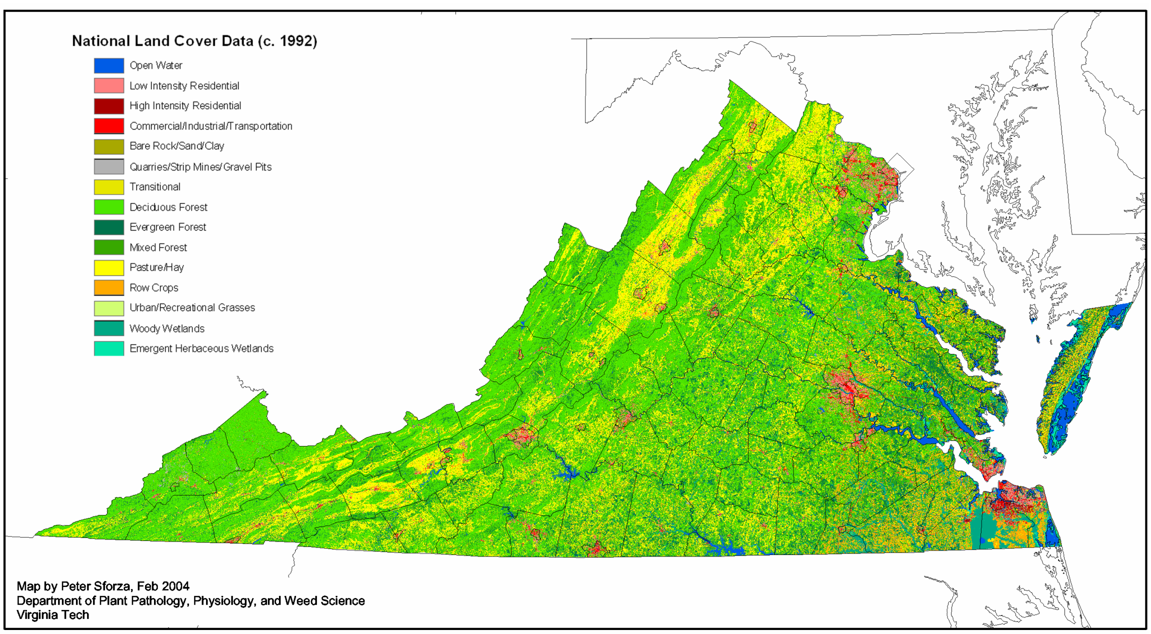


Figure 19. National Land Cover Dataset (c. 1992) (USGS).



Results

Maps for individual components and overall combined suitability are presented below.

Growing season length and climate

Figure 20. Relative suitability classification for annual degree-day (base 50°F) accumulation, used for full season corn calculations.

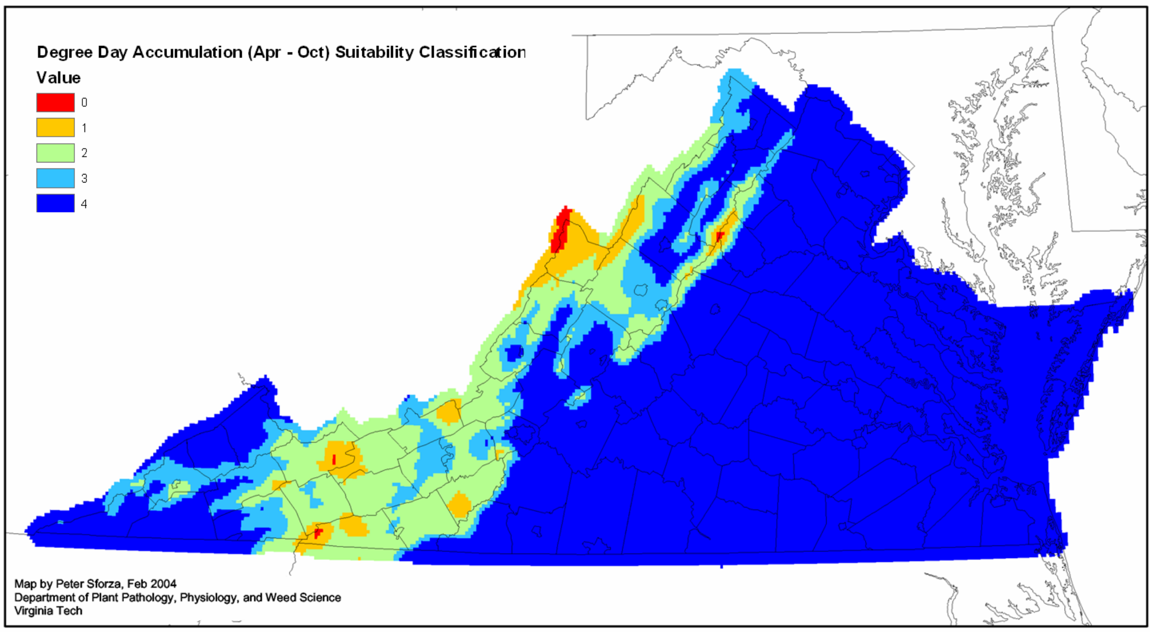


Figure 21. Relative suitability classification for annual degree-day (base 50°F) accumulation, used for double cropped corn calculations.

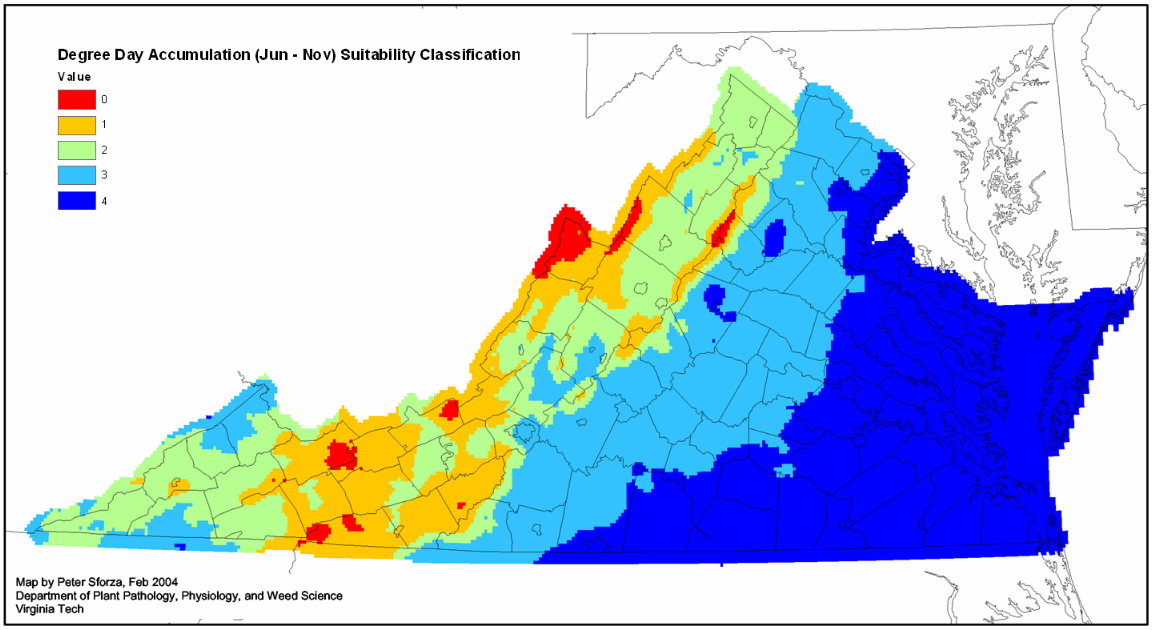


Figure 22. Relative suitability classification for the mean number of frost free days, used for full season corn calculations.

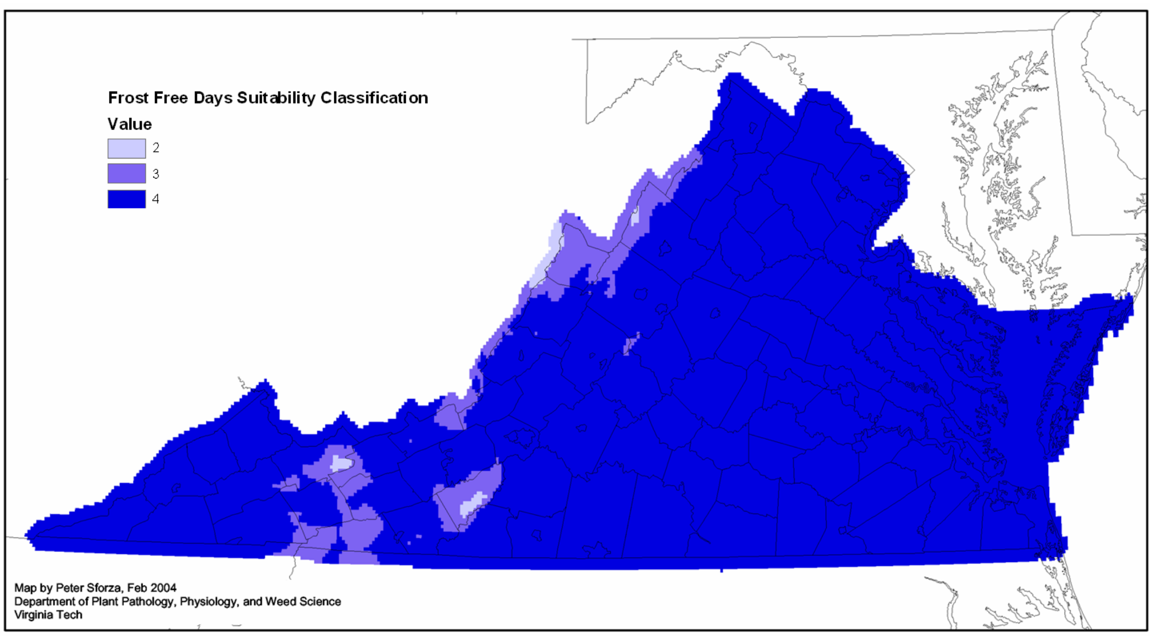
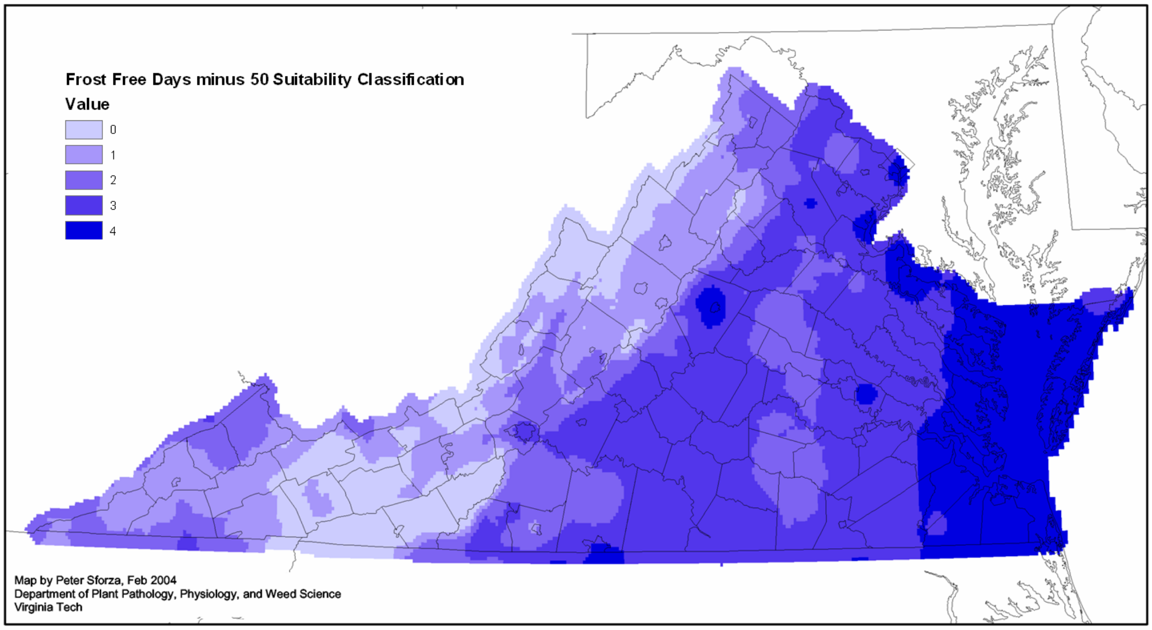
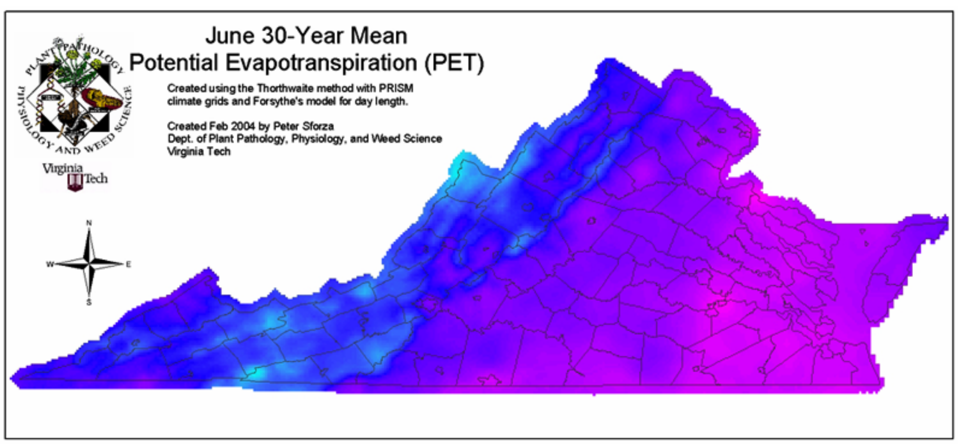


Figure 23. Relative suitability classification for the mean number of frost free days minus 50, used for double cropped corn calculations.



Potential Evapotranspiration and Potential Evapotranspiration minus Precipitation

Figure 24. June 30-year mean Thorthwaite potential evapotranspiration (cm) in Virginia.



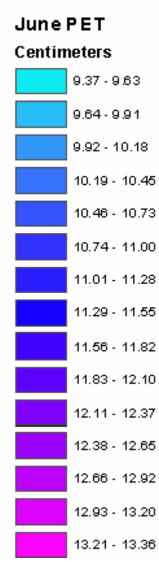
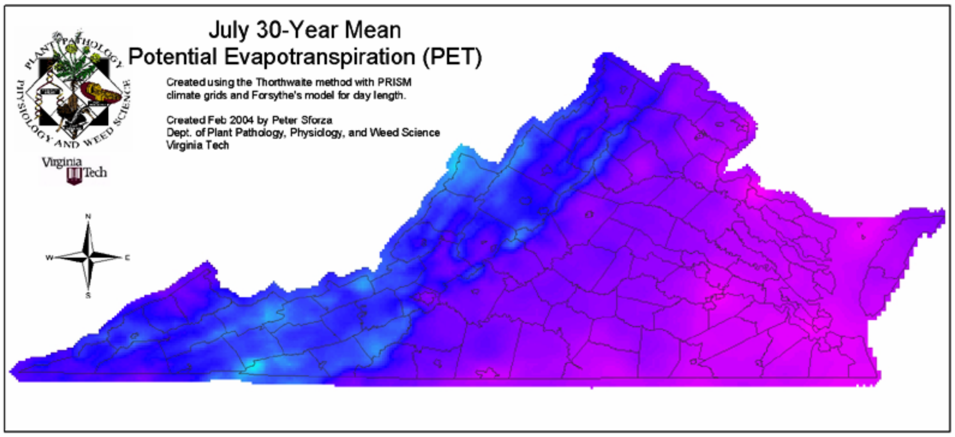


Figure 25. July 30-year mean Thornthwaite potential evapotranspiration (cm) in Virginia.



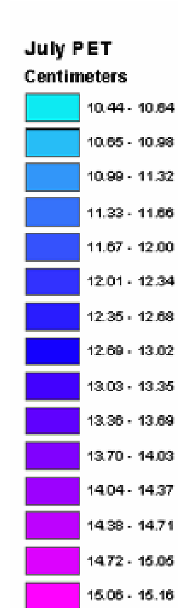
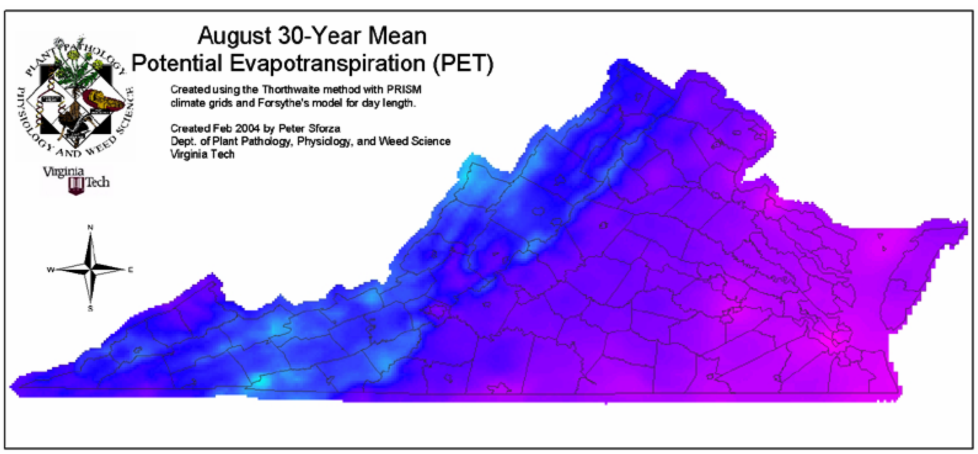


Figure 26. August 30-year mean Thornthwaite potential evapotranspiration (cm) in Virginia.



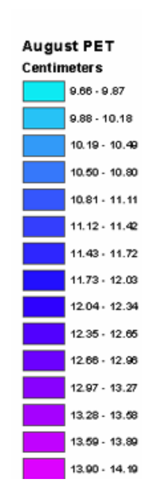


Figure 27. June 30-year mean Thornthwaite potential evapotranspiration minus precipitation (cm) in Virginia.

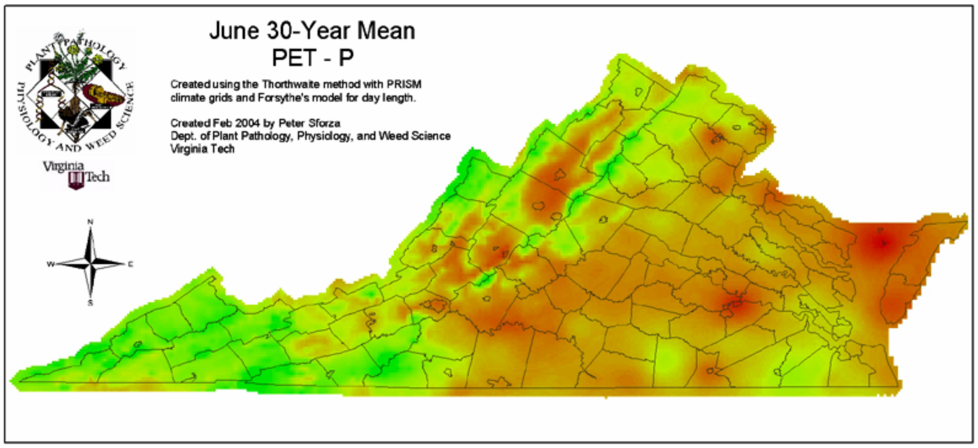
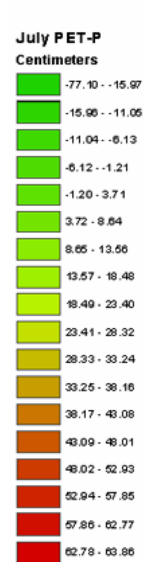


Figure 28. July 30-year mean Thornthwaite potential evapotranspiration minus precipitation (cm) in Virginia.



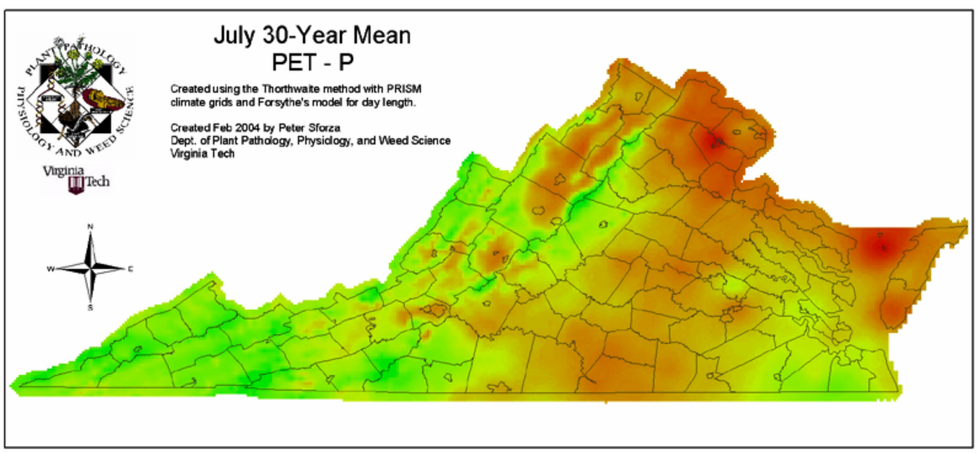
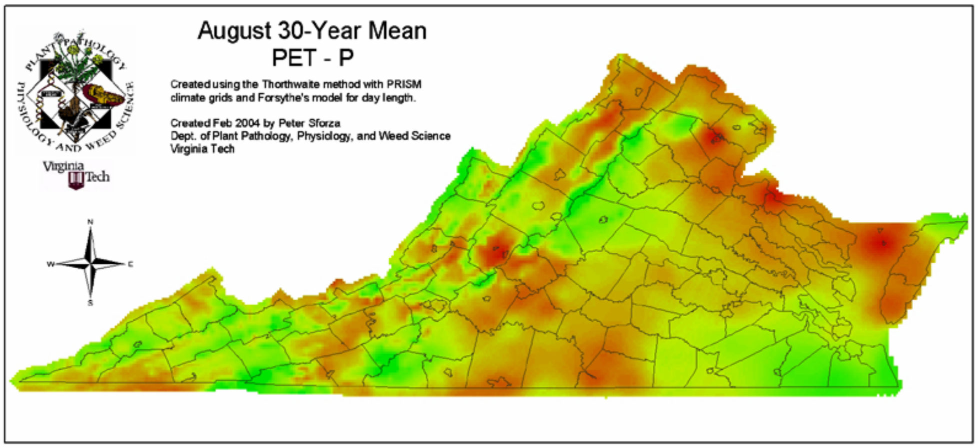


Figure 29. August 30-year mean Thornthwaite potential evapotranspiration minus precipitation (cm) in Virginia.



PET-P during critical stages: silking months

Figure 30. Thornthwaite potential evapotranspiration minus precipitation (cm) during full season corn silking months in Virginia.

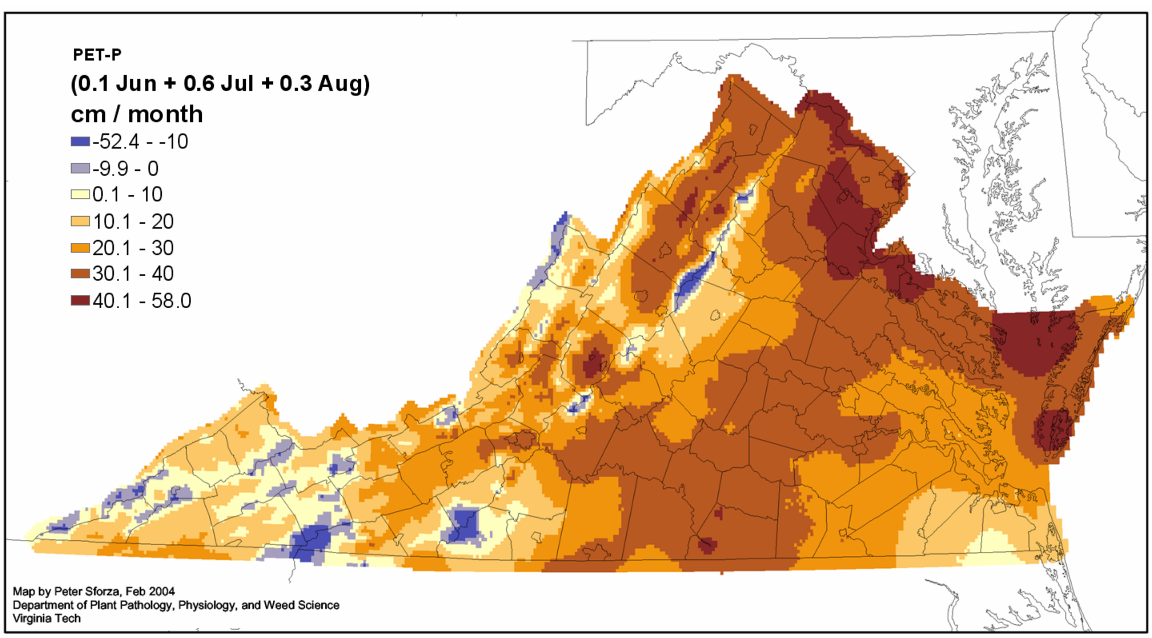


Figure 31. Relative suitability classification for full season corn PET-P for silking months only.

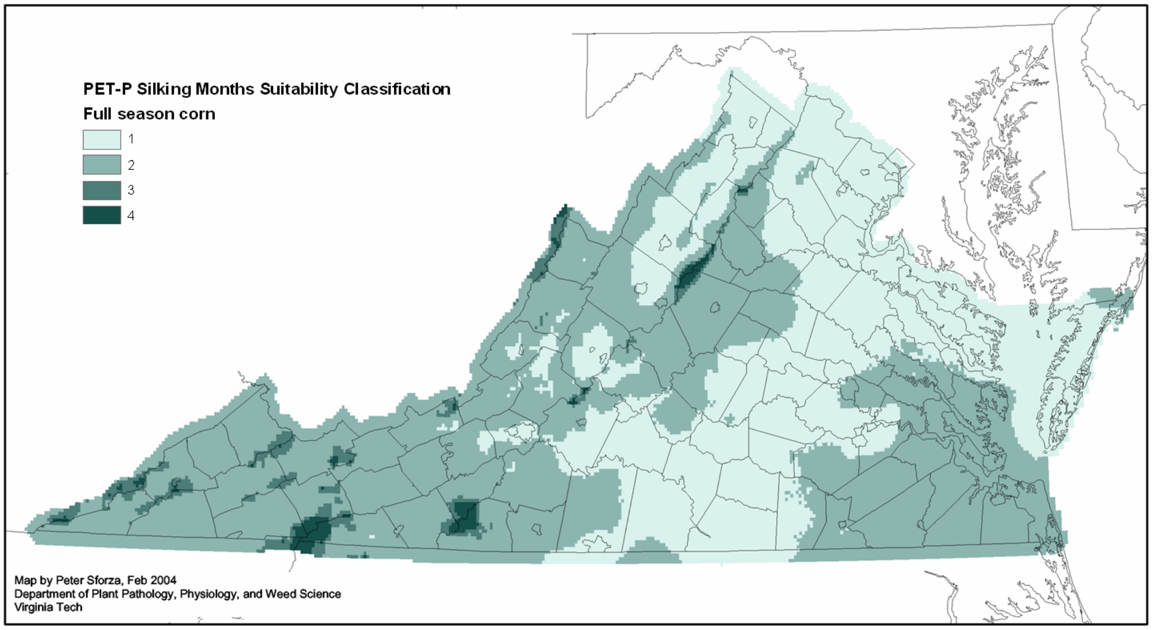


Figure 32. Thornthwaite potential evapotranspiration minus precipitation (cm) during double cropped corn silking months in Virginia.

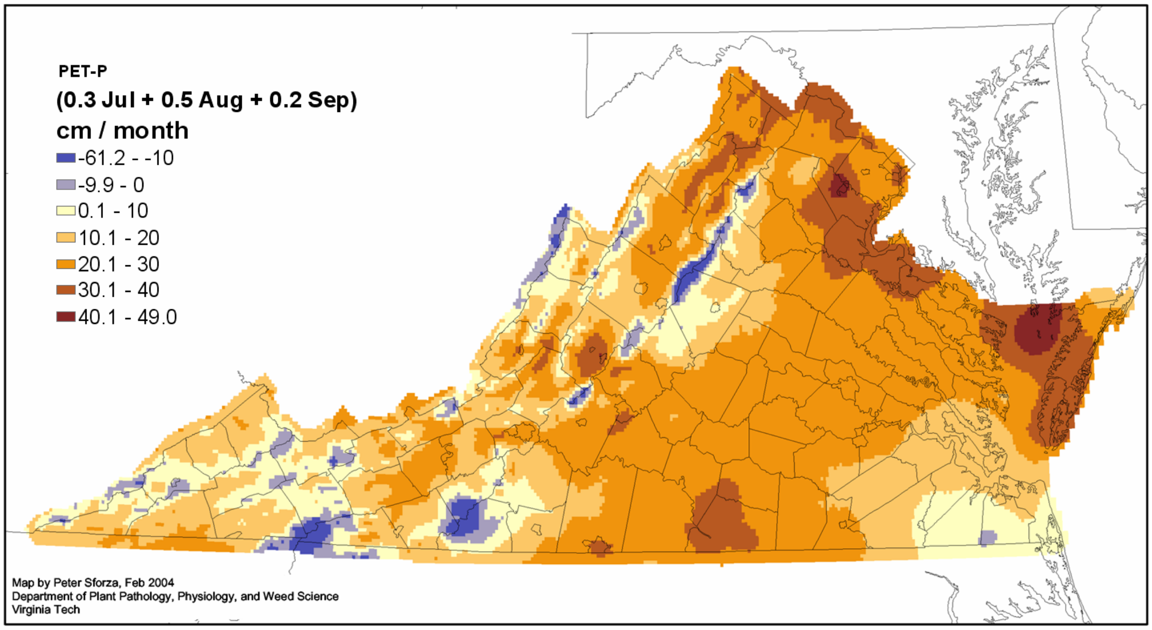


Figure 33. Relative suitability classification for combined double cropped corn PET-P silking months only.

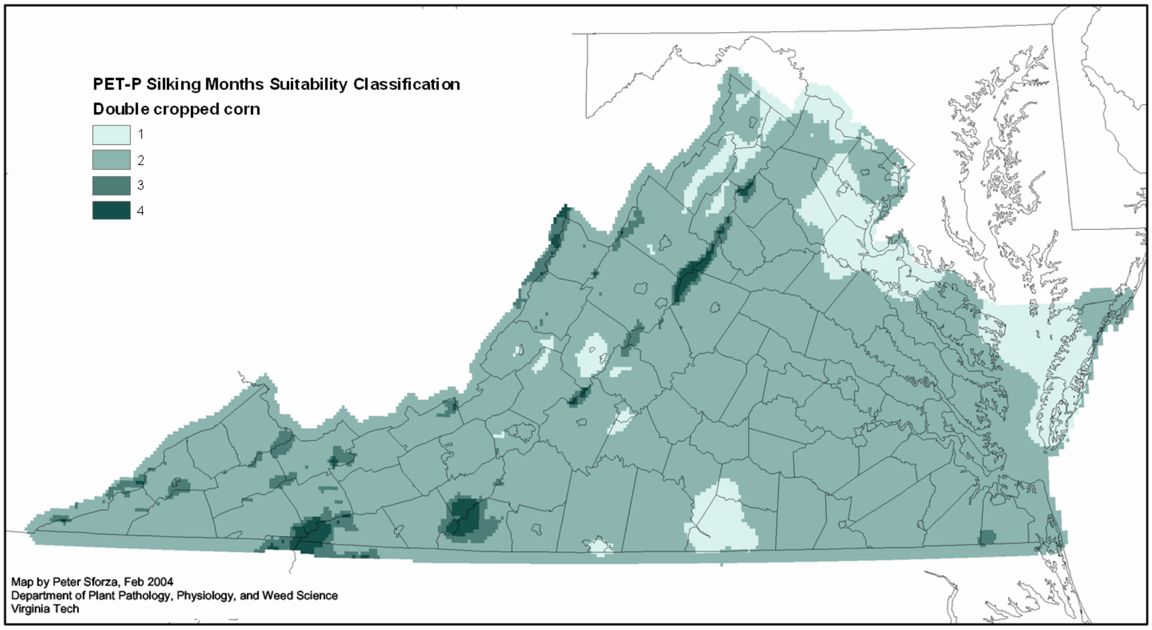
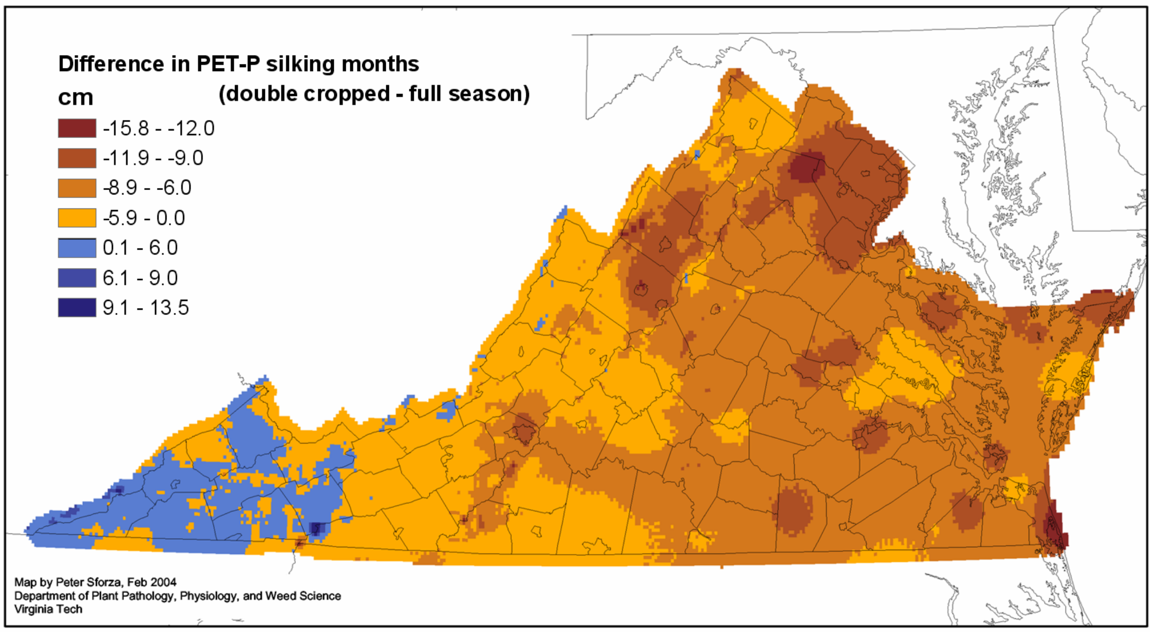


Figure 34. The difference in PET-P expressed as double cropped corn silking months minus full season corn silking months. A negative number indicates that double cropped corn has a lower PET-P than full season corn. This can be interpreted to mean that a negative value indicates the potential advantage of late planted corn in terms of a higher probability of moisture availability during critical silking months.



Soil suitability

Figure 35. Relative suitability classification for soil surface texture used in the analysis.

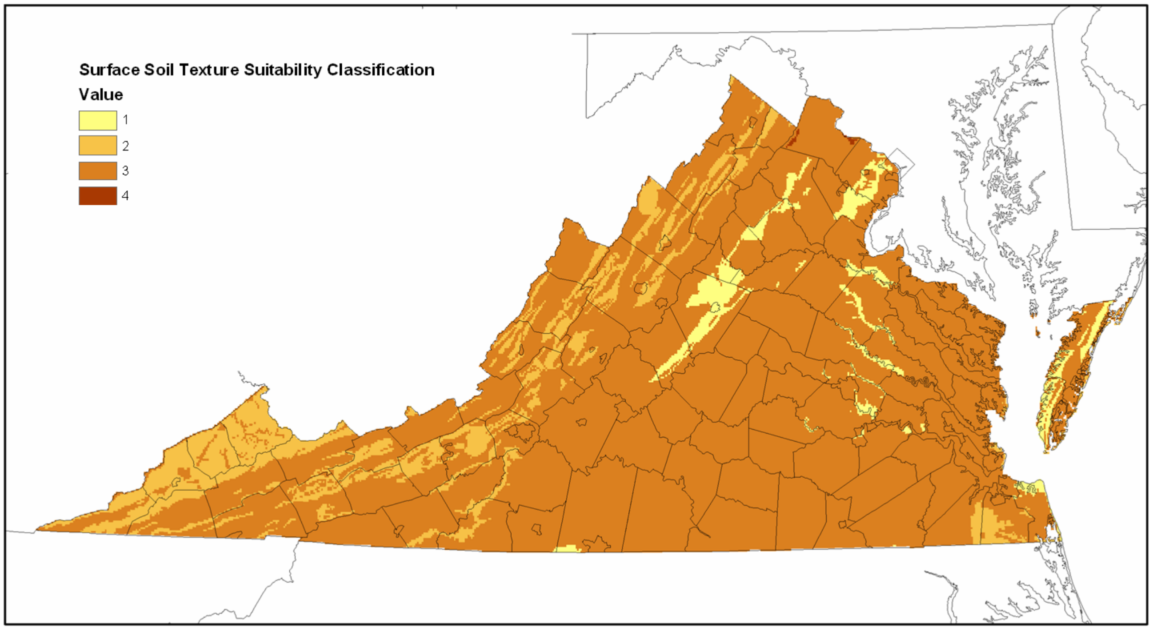


Figure 36. Relative suitability classification for soil drainage used in the analysis.

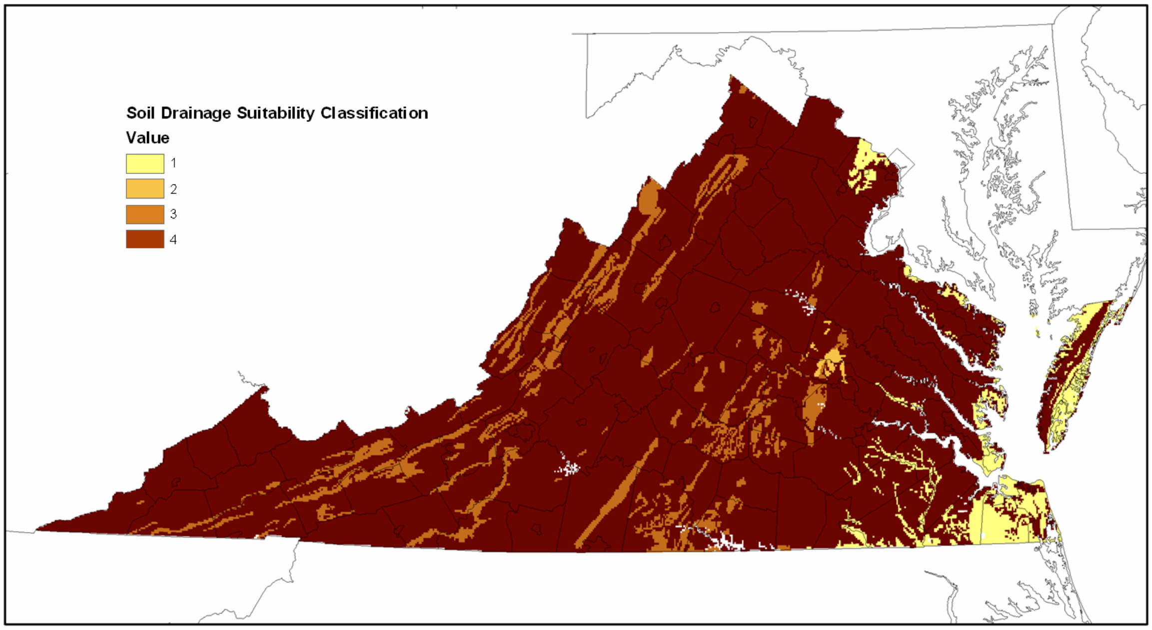
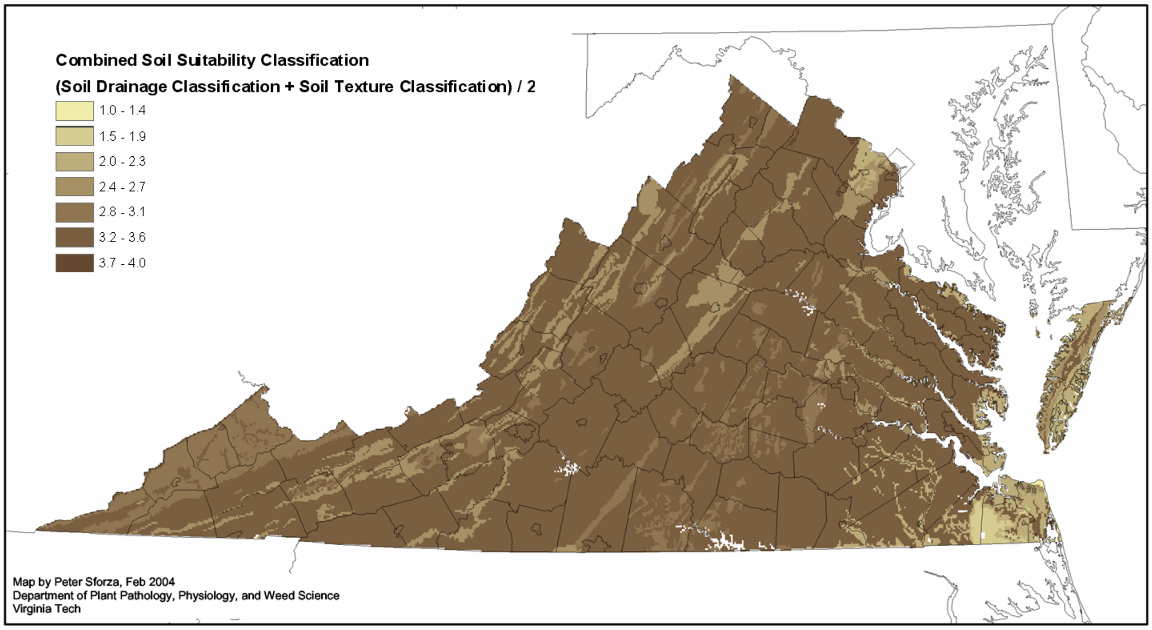


Figure 37. Combined relative suitability classification for soil surface texture and drainage used in the analysis.



Topographic Suitability

Figure 38. Relative suitability classification for percent slope as calculated from NED.

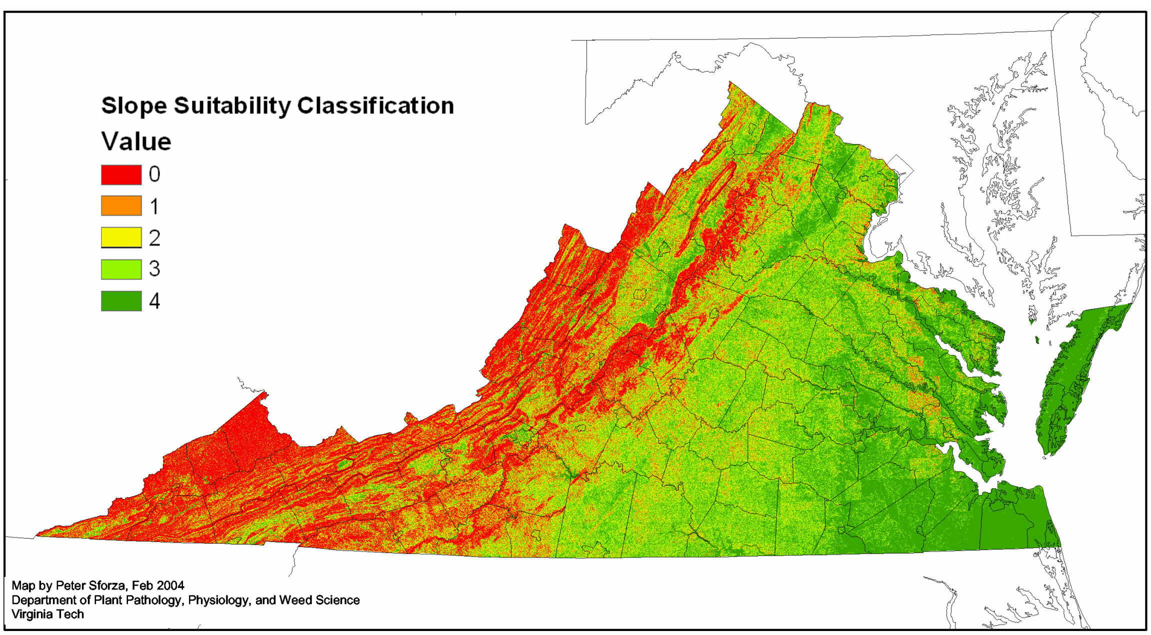


Figure 39. Relative suitability classification for aspect as calculated from NED.

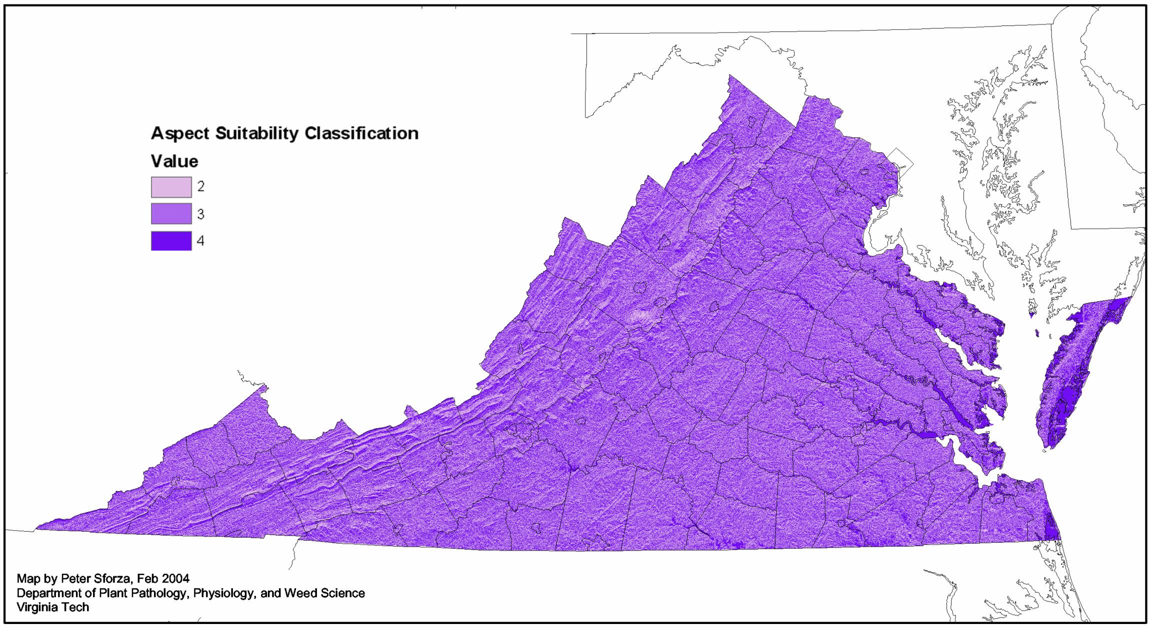


Figure 40. Relative suitability classification for combined full season corn components.

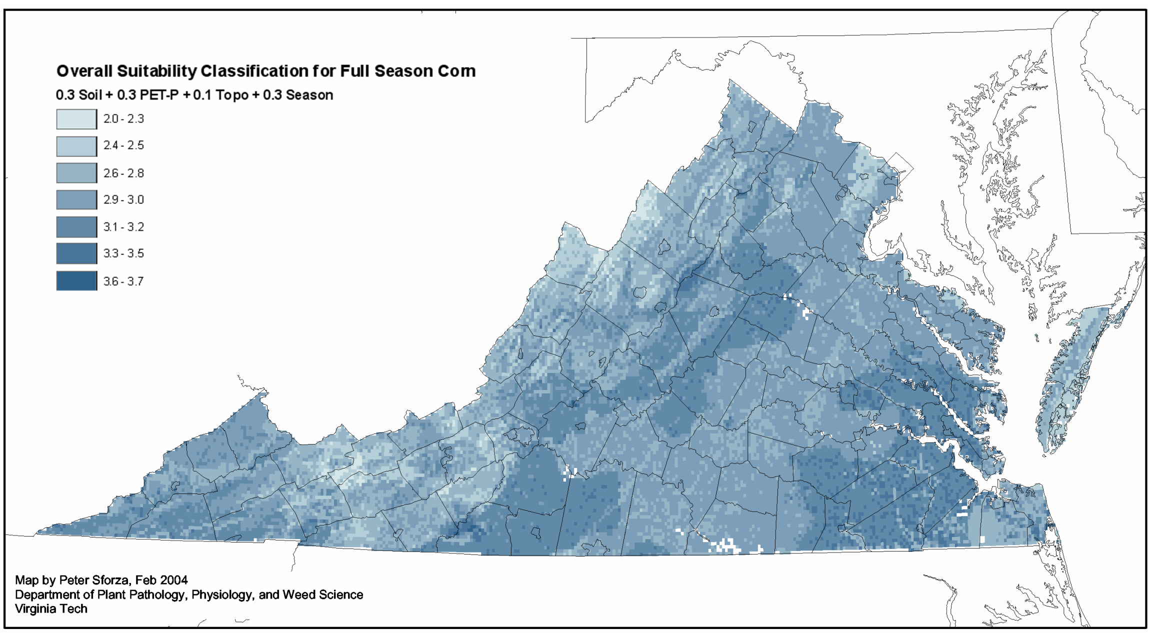
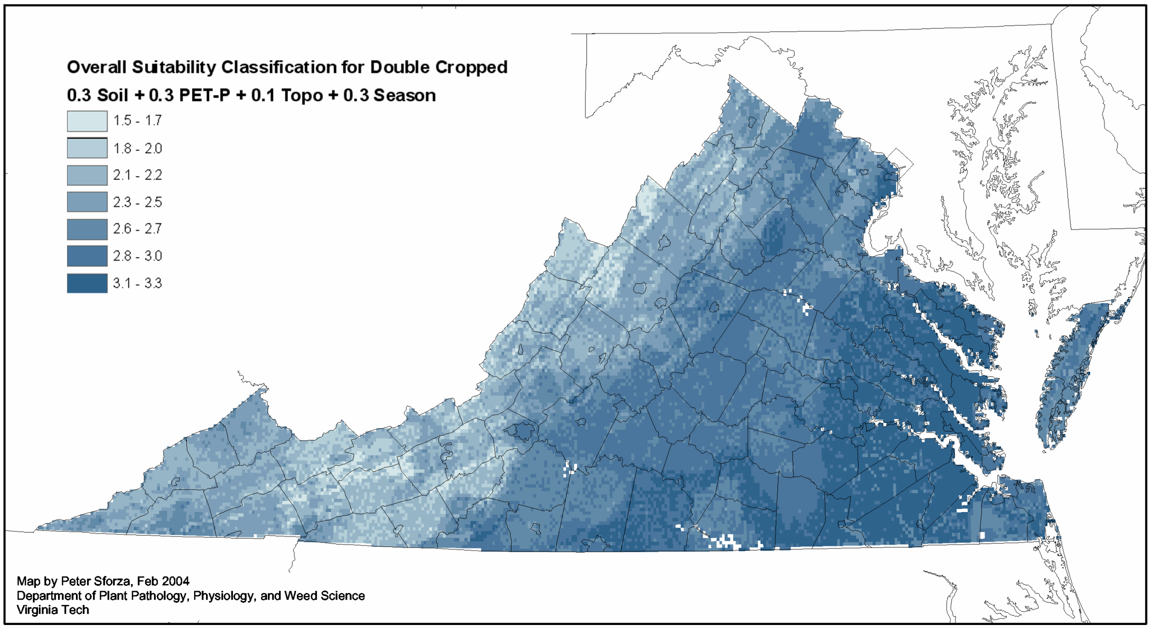


Figure 41. Relative suitability classification for combined double cropped corn components.



Conclusions

The majority of the area of Virginia is suitable for corn production based on the abiotic factors included in this analysis. For double-cropped corn, the short growing season length in western parts of the state is a potentially limiting factor. Differences in moisture availability for full season and double cropped corn are apparent, estimated using 30-year monthly averages for PET-P during silking months. In general, PET-P indicated that double-cropped corn has a potential advantage only in some areas of Virginia in terms of a higher probability of moisture availability during critical silking months when compared to full season corn.