GEOB 270 Final Project
Ta: Wesley Skeeter

Assessing the Potential for Expanding Agriculture in Washington State

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Abstract

Food security is one of the greatest challenges facing the world today. The Food and Agriculture Organization of the United Nations (FAO, 2012) estimated that food demand will be 60% higher by 2050. Increasing agricultural production is therefore crucial. This report uses GIS to assess the extent to which agriculture could be expanded in Washington State, USA with regard to its top 3 cereal grains: wheat, corn and barley. Our analysis establishes which areas would be environmentally suitable to grow these crops, takes into account other competing land uses (namely forest cover, urban development and water bodies) and quantifies how much of this agriculturally viable land is already under production. Our results show that there is indeed potential for agricultural expansion. However, this potential is relatively insignificant for wheat and barley. Whereas, for corn we estimate that over 7 thousand acres have the potential to be brought under production (under natural environmental conditions). This equates to approximately 15% of the total area of Washington state.

Description of Project, Study Area, and Data

Globally, increasing population and affluence are increasing the demand for food. To try to prevent significant food shortages in the future, agricultural production needs to be increased. There are two main ways to accomplish this: 1. agricultural expansion, and 2. agricultural intensification. This report focuses on the first of these two methods with regard to Washington State (WA), in the USA.

Figure 1: Washington State study area

Is Washington State fulfilling its agricultural potential or are there significant areas of suitable agricultural land that are not currently being farmed? GIS analysis is used to assess the extent to which agriculture in WA could be expanded. Our analysis will focus on WA's top 3 cereal crops: wheat, corn and barley. We will use GIS analysis to estimate the extent to which WA's grain production could be increased if all these areas were utilised. We will then examine the significance of this figure in both a local and a global context.

The data used in this report was accessed from a range of web sources outlined in the table below:

Table 1: Information regarding the file names and sources of the data used in this report

Layer description	Layer name	Source	Date
Part 1			
Washington Basemap	WA_County_Bndys	US Department of the Interior Bureau of Land Management	2015
Mean Monthly Temperature	BioClim	WorldClim - Global Climate Data	1960-1990
Mean Monthly Precipitation	BioClim	WorldClim - Global Climate Data	1960-1990
Soil pH	geonode-phihox_m_sl3_250m	World Soil Information Service	2015
Part 2			
Highways	sr24KLines_20151231	Washington State Department of Transportation (WSDOT)	
Forest Cover	landuse10	Ecological Society of America (ESA) Data User Element	2010
Urban areas	CityUGA2016	Washington State Department of Ecology	2016
Tribal Lands	Tribal_Lands	Washington State Department of Ecology	2010
Part 3			
Current crop extent	WSDACrop_2015	Washington State Department of Agriculture	2015

Methodology of Analysis

Our project analysis has 3 main steps:

1. Identify environmentally viable land for production of wheat, corn and barley:
2. Identify environmentally viable land that does not currently have another competing land use.
3. Identify environmentally viable that does not currently have another competing land use and is not already farmed (therefore allowing us to calculate expansion potential)

Part 1:

The mean monthly temperature and precipitation data were downloaded. Corn germinates in the summer (June, July and August), whereas barley and wheat germinate in the fall (September, October, and November). Therefore, the environmental conditions necessary for growth are taken as being the environmental conditions at the time of germination. Therefore, the raster calculator tool was used to average the mean monthly data (from June, July and August) into mean annual values for corn and to average the mean monthly data (from September, October and November) into mean fall values for wheat and barley. Each of the three layers (precipitation, temperature and pH) was then reclassified as being either environmentally viable for crop growth, or not viable using the criteria listed in *Table 2*. After reclassification the data were transformed into vector polygons. These three reclassified layers were then intersected to identify all the areas that are environmentally viable according to all three environmental parameters for each crop. A separate map was generated for each crop.

Table 2: Environmental conditions necessary for the growth of wheat, corn and barley (see bibliography for reference)

Crop Type	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)	pH
Wheat	> 100	12.0 - 25.0	5.6 - 7.0
Corn	> 127	10.0 - 15.6	5.6 - 7.1
Barley	> 78	12.0 - 23.8	5.6 - 7.2

Part 2:

The competing land uses taken into account in this stage of the analysis are forest cover, urban development and water bodies. The state highway network is also displayed for reference but not taken as a significant competing land use. The data layers regarding each of these layers were downloaded. The cities and state highway network layers were already isolated to Washington State. However, the waterbodies data and global land cover data had to be clipped to the Washington state boundary. Furthermore, the global land cover layer displayed a wide range of different land cover types. Therefore, the layer was reclassified into a binary "forest" or "not forest", as outlined in *Table 3*. The reclassified layer was then converted into a vector polygon.

The forest cover, urban development and water bodies land use layers were then all intersected with the total environmentally viable growth area, for each crop, identified in *Part 1*. The total environmentally viable area minus this intersection equals the total area of environmentally viable land that is not currently occupied by another competing land use.

Table 3: Forest reclassification criteria

Object ID	Description
Forest	
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
50	Closed (>40%) broadleaved deciduous forest (>5m)
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	Closed (>40%) needleleaf evergreen forest (>5m)
90	Open (15-40%) needleleaf deciduous or evergreen forest (>5m)
100	Closed to open (>15%) mixed broadleaved and needleleaf forest (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
Not Forest	
11	Post-flooding or irrigated croplands (or aquatic)
14	Rainfed croplands
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
130	Closed to open (>15%) (broadleaved or needleleaf, evergreen or deciduous) shrubland (<5m)
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
150	Sparse (<15%) vegetation
190	Artificial surfaces and associated areas (Urban areas >50%)
200	Bare areas
210	Water bodies
220	Permanent snow and ice
230	No data (burnt areas, clouds,...)

Part 3

A data layer was downloaded that related to the current cultivation extent of all crop groups currently grown in Washington state. This was an extremely large file which caused ArcGIS to keep crashing. To overcome this problem we used the 'dissolve' function to create a smaller layer that only included the crop group 'cereal grains'. However, for this analysis it was necessary to isolate specific crop types, not just crop groups. Objects in the WSDACrop_2015 layer were only assigned a crop group. Therefore this layer was joined with a data table that contained the same objects and also included the information outlining which crop type they belonged to. The two layers were joined according to the spatial reference attribute 'TRS'. The layer was then dissolved again for 'crop type'. The 'Select by Attributes' function was then used to individually isolate wheat, corn and barley, one after another. A new data layer was then created displaying the spatial extent of current cultivation of each crop.

The purpose of this stage of analysis was to account for the fact that some of the potential cropland identified in *Part 1 and 2* is already being farmed. Therefore, potential cropland does not equate to expansion potential. To account for this, the total potential area for each crop was clipped to the current crop area. This created a new layer which displayed agriculturally viable land that is not already being farmed.

Discussion and Results

1. ***Identifying Environmentally suitable land areas:***

The maps below show the areas of Washington state that are suitable for growth of barley, corn, wheat, under natural conditions, according to the three environmental parameters accounted for: mean annual temperature(°C), mean annual precipitation (mm) and pH. It is clear from these maps that the precipitation and temperature conditions required for corn growth are much more widespread than they are for wheat and barley. Almost the entire state has an appropriate temperature for corn growth, whereas for wheat and barley only two small strips of land in the west of the state are suitable. The pH tolerance range is the same for all three crops. Therefore, this is the primary limiting factor for corn growth.

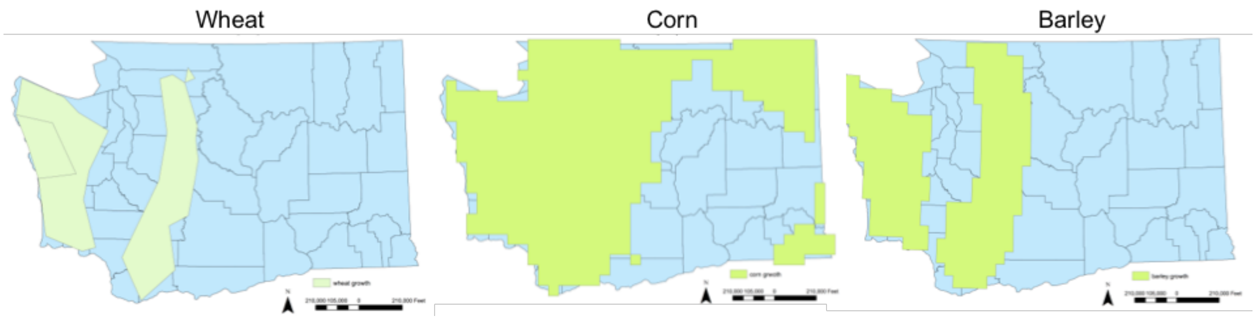

Figure 2: Areas suitable for growth according to mean annual precipitation (mm)

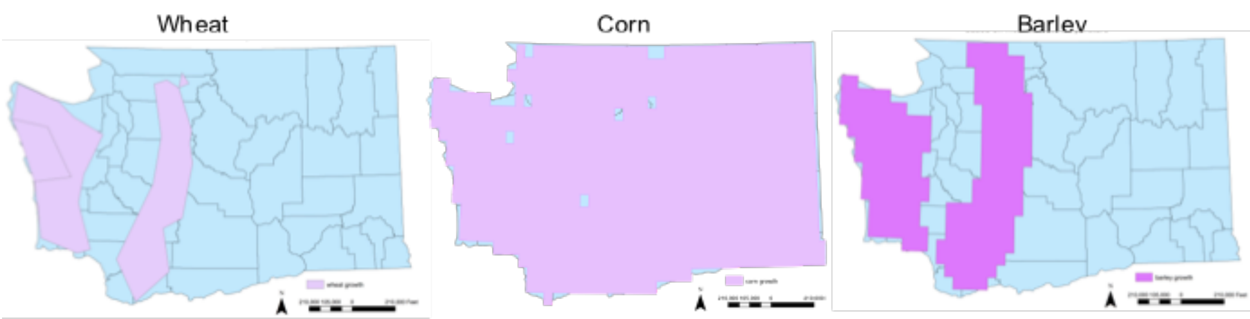

Figure 3: Areas suitable for growth according to mean annual temperature (°C)

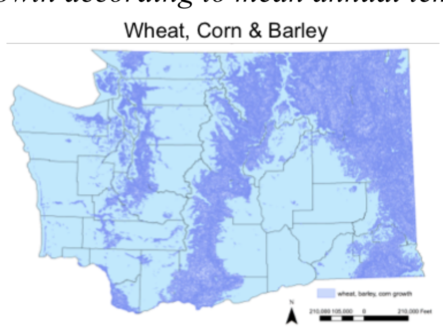

Figure 4: Areas suitable for growth according to pH (NB. all three crops have the same pH range)

The following three maps show the areas suitable for growth according to all three environmental parameters. It is clear from these maps that under natural environmental conditions and when only these three parameters are taken into account, Washington State is most suitable for growing corn, and much less suitable for growing wheat and barley. Only very small areas are viable for wheat and barley, and these are isolated patches in the west of the state.

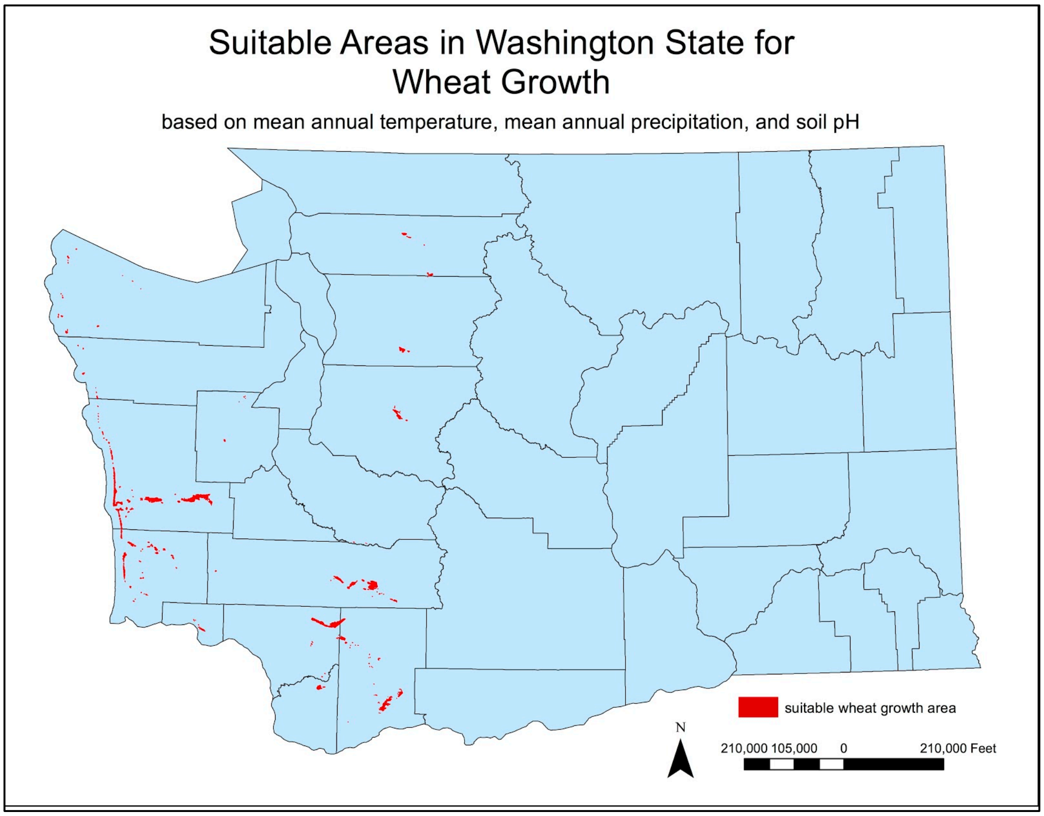

Figure 5: Map showing environmentally viable areas for wheat growth in Washington State

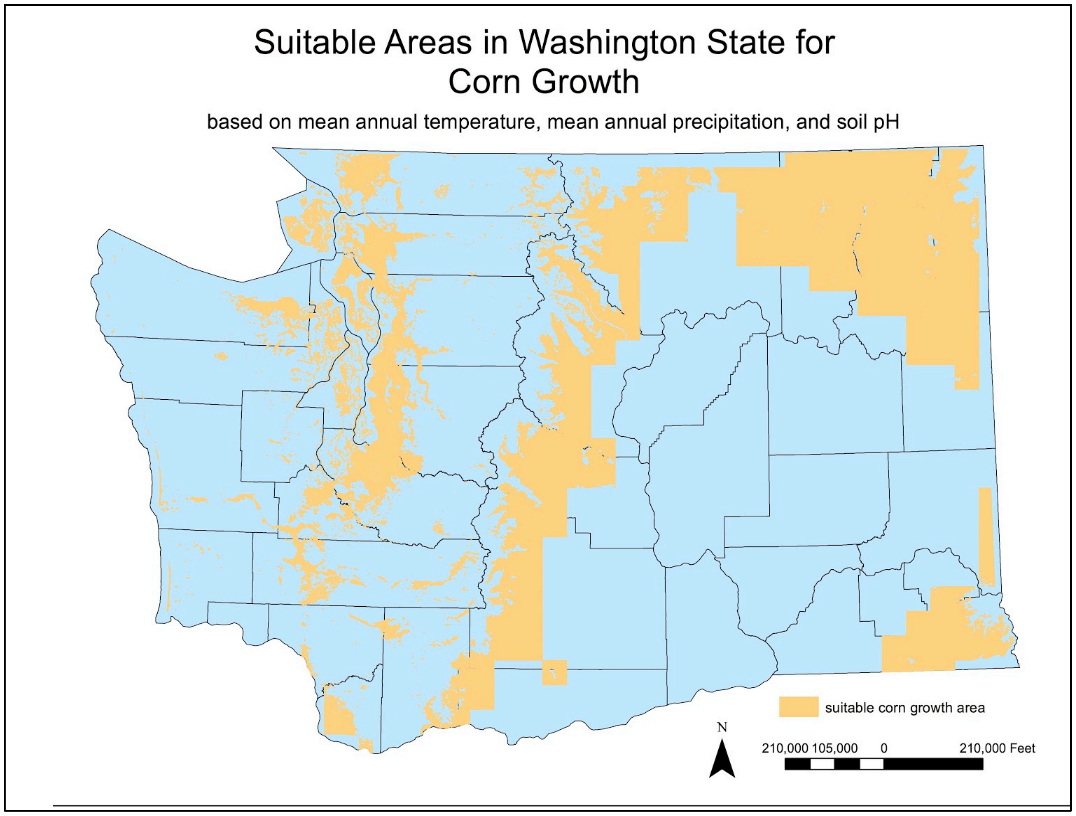

Figure 6: Map showing environmentally viable areas for corn growth in Washington State

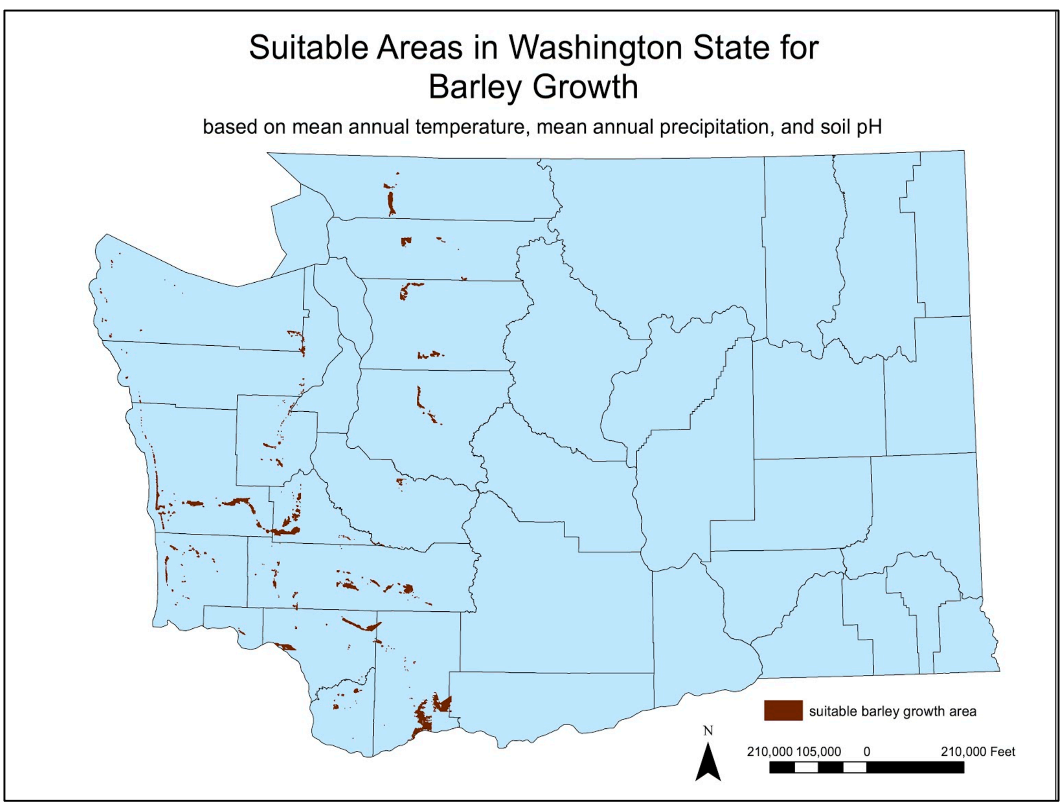

Figure 7: Map showing environmentally viable areas for barley growth in Washington State

The area of land (in acres) that is environmentally viable for each crop was summed and displayed in the *Table 4* below, according to both each individual environmental parameter and all three together. This area was then converted into a percentage of the total area of Washington State (45,663,332 acres) in *Table 5*.

Table 4: Areas of land that are environmentally suitable for crop growth according to the three environmental parameters investigated.

Environmental Parameter	Environmentally suitable area (% of Washington state)		
	Wheat	Corn	Barley
Mean Annual Precipitation (mm)	8,948,036	28,385,483	1,321,805
Mean Annual Temperature (°C)	31,536,391	44,502,079	31,536,387
Soil pH	15,908,361	15,908,361	15,908,361
All of above	63,525	9,949,521	178,831

Table 5: Environmentally suitable land areas as a % of total area of Washington State

Environmental Parameter	Environmentally suitable area (% of Washington state)		
	Wheat	Corn	Barley
Mean Annual Precipitation (mm)	19.59	62.16	28.95
Mean Annual Temperature (°C)	69.06	97.45	69.06
Soil pH	34.84	34.84	34.84
All of above	0.14	21.79	0.39

Our analysis has calculated that only a very small area of Washington State is viable for growing wheat and barley under natural environmental conditions, 0.14% and 0.39% respectively. This is extremely surprising given they are the first and third largest cereal grains grown in the state. Even more surprising is that over 21.79% is viable for growing corn, under natural environmental conditions. This is just under a quarter of the entire state area!

However, it is important to note that these three parameters may not be the only factors influencing crop growth. There are other environmental and non-environmental factors that can limit crop growth, such as soil nutrient content, soil water retention capacity, soil depth, competition and predation. Furthermore, we used annual mean for temperature and precipitation as our environmental criteria. However, perhaps extreme values (i.e. maximum and minimum values) are more limiting to crop growth. Finally, very little agriculture is actually conducted under natural environmental conditions, artificial fertilizers, irrigation and liming agents can all be used to overcome environmental limitations, at a certain economic cost.

2. Environmentally suitable areas taking into account other land uses:

Table 6 shows the total areas of Washington State that fall under each of the four land use categories taken into account in this study: tribal lands, cities, water bodies and forest. From these results it is clear that the dominant non-agricultural land use is forest, at over 26 thousand acres. The other land use areas range from 1 to 3 thousand.

Table 6: Different Land uses (acres) in Washington State

Landuse Type	Area (to nearest acre)
Tribal Lands	3,330,828
Cities	1,581,405
Water Bodies	3,852,985
Forest Cover	26,088,341

The following maps display forest cover, urban developments, water bodies and the area of environmentally viable land that does not currently have another competing landuse (in red).

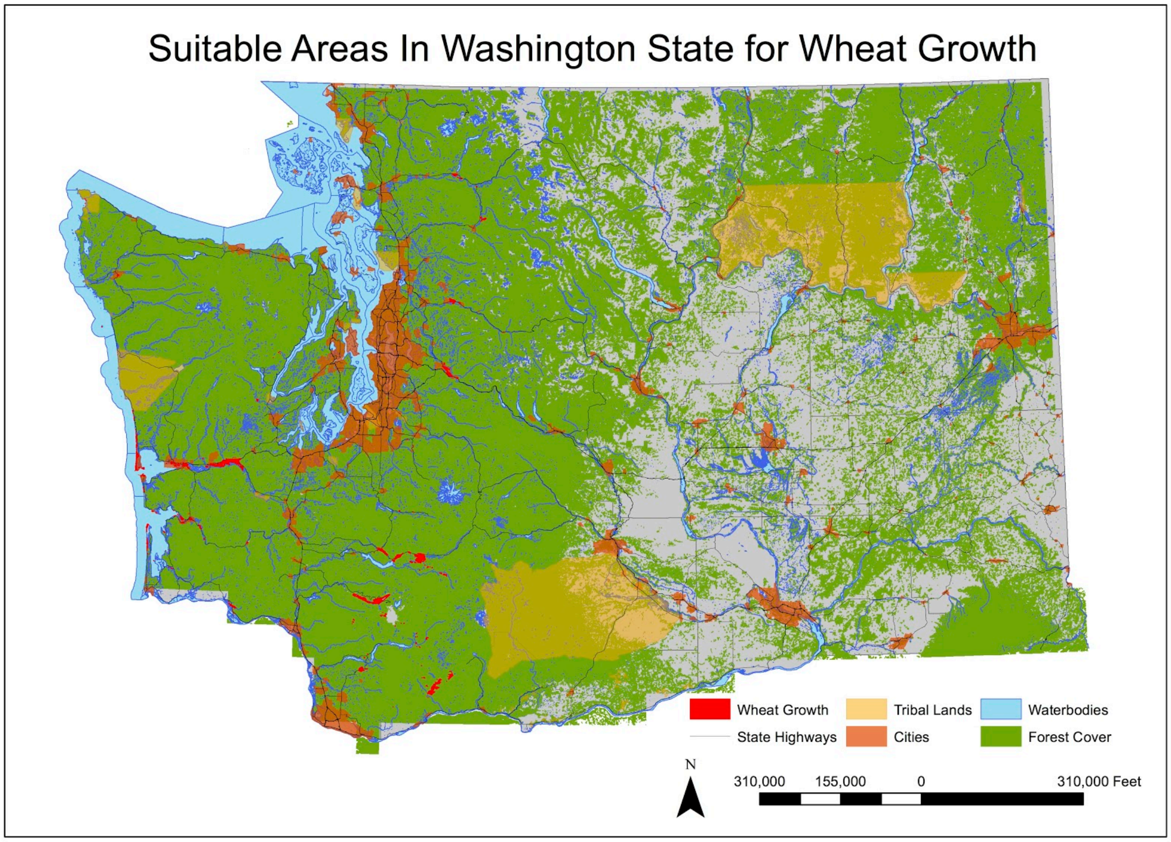

Figure 8: Map showing environmentally viable areas for wheat growth in Washington State and competing land uses (namely forest cover, water bodies and urban development)

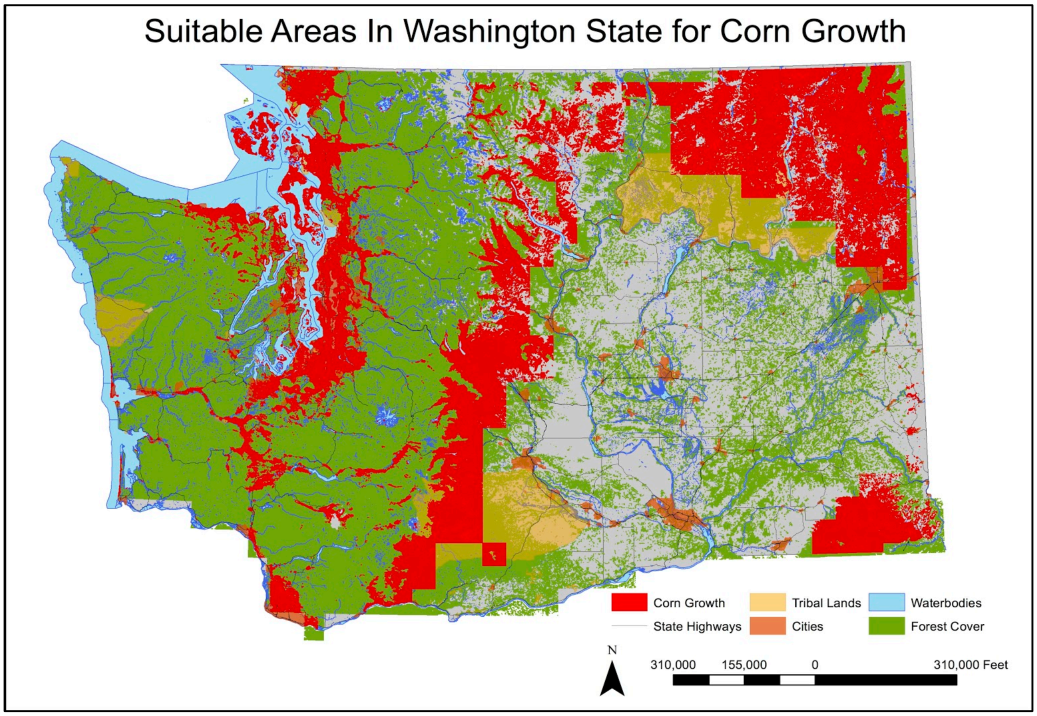

Figure 9: Map showing environmentally viable areas for corn growth in Washington State and competing land uses (namely forest cover, water bodies and urban development)

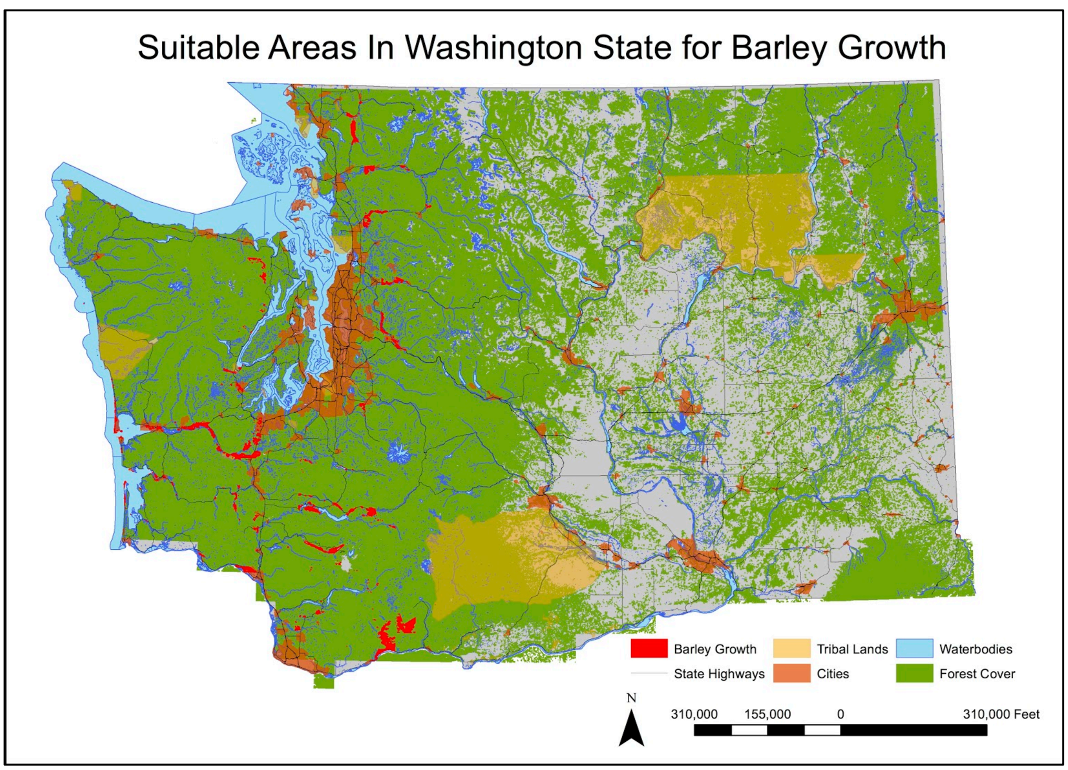

Figure 10: Map showing environmentally viable areas for barley growth in Washington State and competing land uses (namely forest cover, water bodies and urban development)

As forest is the dominant competing land use, this raises questions as to whether agriculture should be prioritized over forest cover in some areas and the land use converted accordingly. However, state regulation and environmental protection legislation limit deforestation. Furthermore, in Washington state, privately-owned forests are required to adhere to the same standards (WFPA). The main arguments against permanent deforestation are environmental and economic. Environmentally, ecosystems may be detrimentally affected and economically timber is often more valuable than arable crops. Perhaps, an assessment is needed of the environmental and economic trade-offs between these different land use types.

Table 7 shows the total area of land that is environmentally suitable for growing each of the three crops once competing land uses are taken into account. As we would expect, these values are lower than the values we had before. Nevertheless, the same trends remain apparent: corn has the highest viable area at 15.83%, followed by wheat at 0.1% and then barley with 0.33%. This 15.83% for corn is still a very significant area of land.

Table 7: Environmentally suitable areas of that land are not currently not occupied by another competing land use

	Crop Type		
Area	**Wheat**	**Corn**	**Barley**
To nearest acre	43,894	7,228,177	151,322
As % of Washington State	0.10	15.83	0.33

However, we have only taken into account land that is directly used in a specific competing land use. Yet, sometimes land surrounding these areas may be affected, despite not being directly under that land use. For example, proximity to urban areas may indirectly reduce agricultural viability due to pollution. There is plenty of land near urban centres that environmentally speaking are viable crop-growing areas.

3. Agriculturally viable areas not currently under production:

The following maps display the agriculturally viable areas identified in *Part 2*, alongside the areas where each crop is currently grown. This allows a comparison of potential and current crop growth.

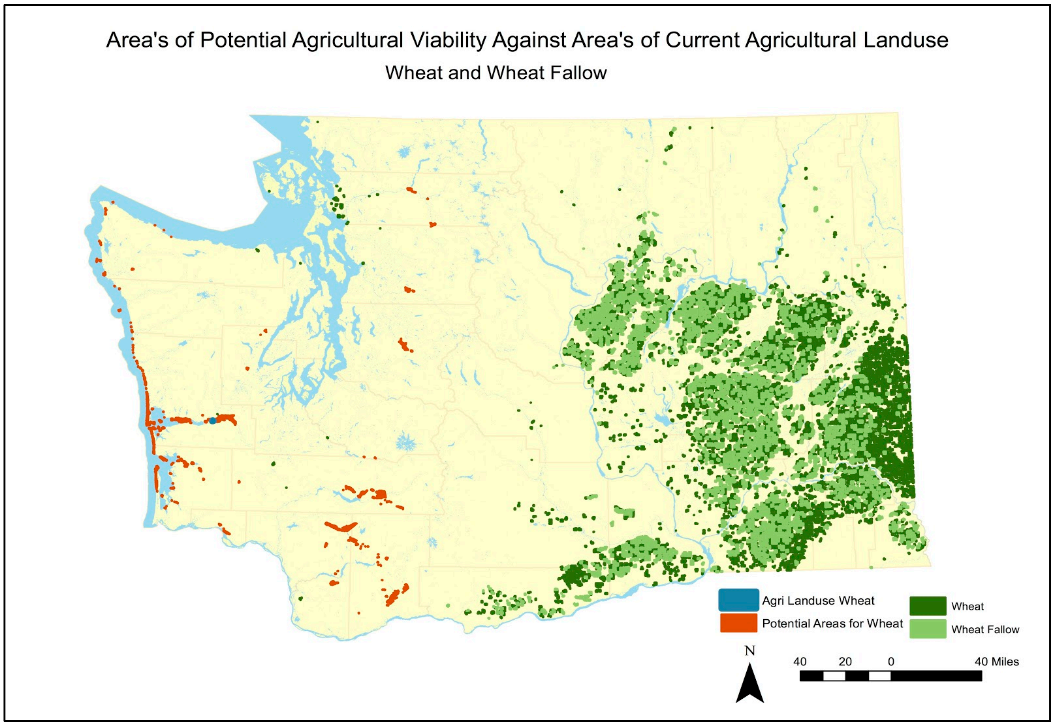

Figure 11: Map to show potential and current areas for wheat growth, as well as the areas where these two land uses overlap (referred to as "Agri Land use")

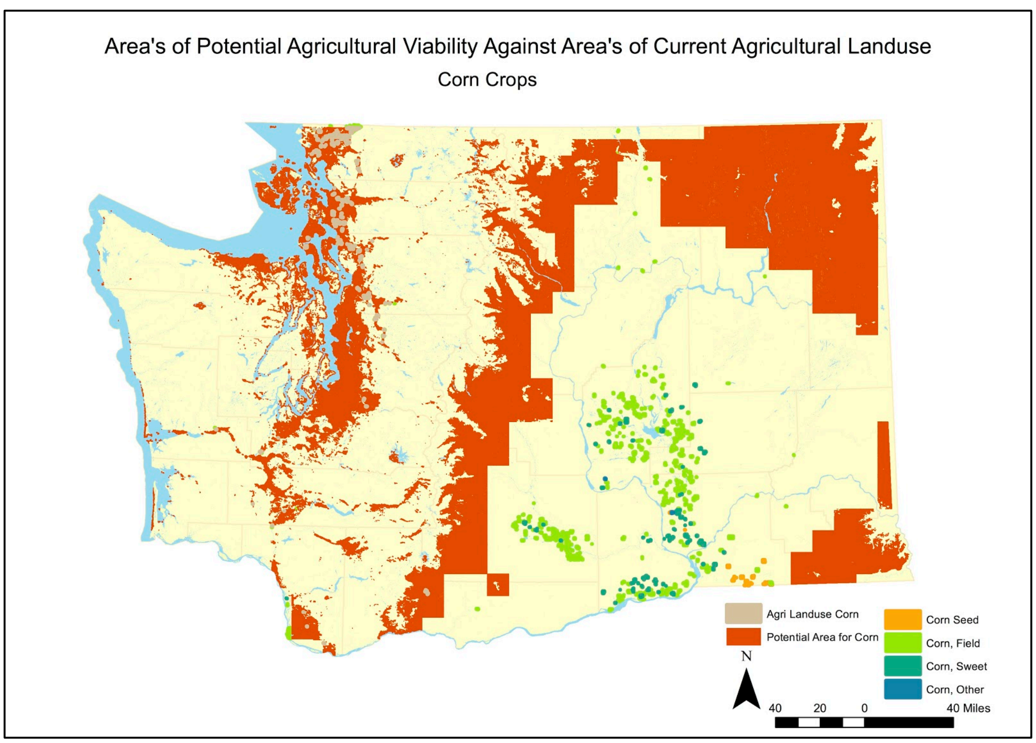

Figure 12: Map to show potential and current areas for corn growth, as well as the areas where these two land uses overlap (referred to as "Agri Land use")

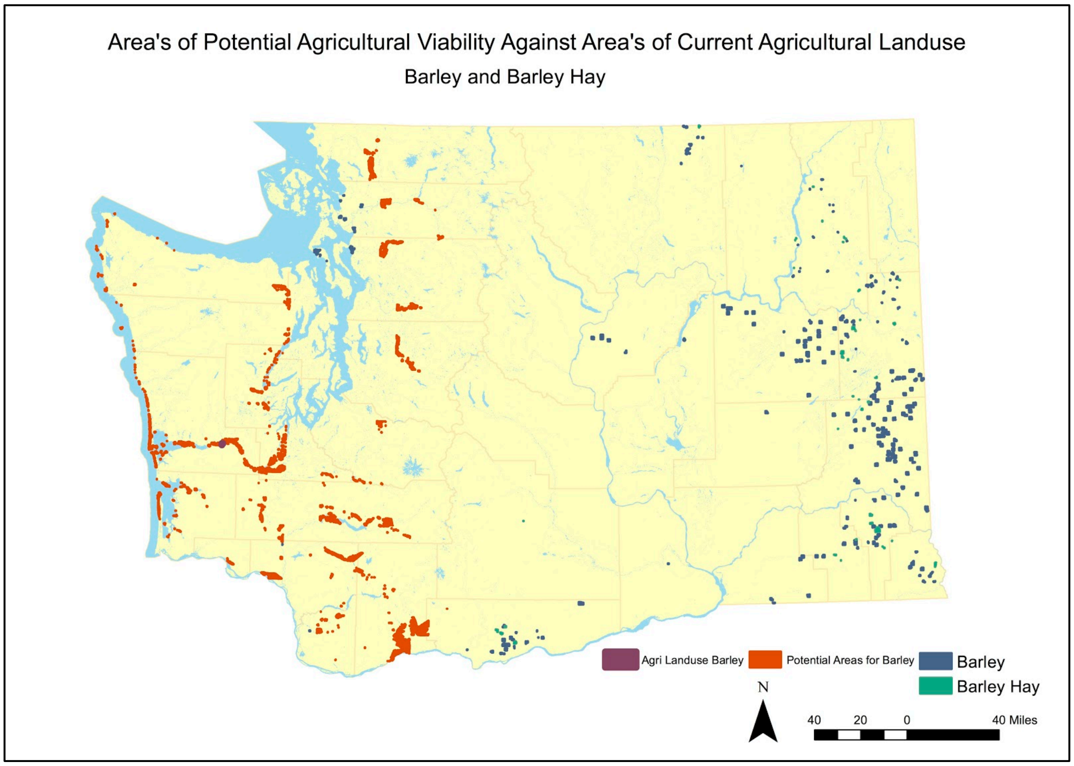

Figure 13: Map to show potential and current areas for barley growth, as well as the areas where these two land uses overlap (referred to as "Agri Land use")

Table 8:

Area (acres)	Crop Type Wheat	 Corn	 Barley
Total area of current crop growth	3359824	97139	150618
Total area of potential crop growth	43,894	7,228,177	151,322
Total area of overlap between current and potential	87	93,086	80
Expansion potential (total area of potential - total area of overlap)	43,807	7,135,091	151,242

Area (as a % of total Washington State area)	Crop Type Wheat	 Corn	 Barley
Total area of current crop growth	7.36	0.21	0.33
Total area of potential crop growth	0.10	15.83	0.33
Total area of overlap between current and potential	0.00	0.20	0.00
Expansion potential (total area of potential - total area of overlap)	0.10	15.63	0.33

From these maps it becomes clear that the current extent of agriculture is not limited to areas which are viable under natural environmental conditions. This is because artificial fertilizers, soil liming agents, and irrigation systems can are utilized to overcome environmental limitations. The majority of these 3 cereal grains are currently grown in the southeast of Washington State, yet our analyses suggest that this is not a viable area for growth under natural environmental conditions from *Parts 1 and 2*.

Intriguingly, the areas that our analysis suggests are the most environmentally viable are not currently cultivated; there is very little overlap, only 87 and 80 acres for wheat and barley respectively. The value is higher for corn at 93086 acres. We have identified the west coast area as the best area for growth due to more annual precipitation and high temperature. This suggests that there is indeed potential for agricultural expansion in Washington State.

There are two main possible reasons that may account for this overlap: the fact that limitations of environmental parameters can now be overcome artificially and the fact that topography was not taken into account. For example, land that is more accessible, but less naturally environmentally viable may be prioritized for farmland over land that is inaccessible and but environmentally viable. Artificial fertilizers, irrigation and other soil amendments may be used to bring environmental conditions into crop tolerance ranges. These technologies became particularly advanced after the Second World War. These techniques and technologies are likely what enable wheat and barley to be grown in areas that we have identified as environmentally unsuitable. Furthermore, in addition to affecting temperature and precipitation (both of which were accounted for in this analysis) topography can influence sunlight availability. Areas that are too steep are also unsuitable for planting. Therefore, some of the areas that we have identified as agriculturally viable, may not in actual fact be viable in reality.

For barley and wheat these areas are relatively small in relation to the total area of the state, therefore cultivation of these crops would not be expanded significantly even if all of these areas came into production. Wheat currently has a large current production extent, namely 3359824 acres, (the largest, by far, of all three crops) yet the smallest amount of expansion potential, only 0.10%. However, for corn the opposite is true. Its current production extent is much lower than wheat, namely 97139. Yet the areas in which it is environmentally viable are huge. Consequently, it has an expansion potential of 15.63%. If all of these areas were brought into production corn cultivation could easily outpace the leading cereal grain.

Furthermore, as previously mentioned our analysis only took into account agricultural viability under natural environmental conditions. Yet, techniques now exist to bring areas that are not viable under natural environmental conditions into production, often at a marginal cost. Therefore, the expansion potential for all three crops, particularly wheat and barley, may in fact be larger than we have calculated.

Error and Uncertainty

When picking the variables that are needed to map, the group chose based on their best judgements what variables are worth showing and working with to compile the needed conclusions and analysis.

When converting a raster dataset to a vector, some generalization takes place. As raster shapes are based on pixels, the polygons after conversion are converted into those straight-edged shapes, changing the shape versus the real-world shape of the object. Meaning data was potentially lost. As well, the new vector polygon shape is simplified which changes the boundaries, creating a classification error. A raster set is one shape, and when converted into a vector consisting of many polygons, there is a loss of topological connectivity between the new sets of polygons. Possibly corrupting the data, and losing information.

There is a risk of error regarding the metadata sets from our data sources. We suspect that some data was lost, repetitive or not a complete data set. In layers like global land cover, we segregated attributes that represented different types of forest cover. Yet, segregating those attributes required human discretion, and some of those attributes may have included unneeded or repetitive data. Our team faced a number of issues with effectively isolating crops and needed to come up with different flowcharts to efficiently dealing with the largest attribute table we've manipulated to date.

Also, the layer global land cover, and the layer representing water, had issues where one had to choose whether to show all water or all global land cover (forest cover) in Washington State when layering the two layers. The group chose to show all water, which meant that the San Juan Islands in north-western Washington State show up on the maps as just water, adjusting the attribute data of how much forest cover truly exists in Washington State marginally --- a form of error in representing the spatial data. Yet, with our bias, we felt that there was no plausible way to farm on the islands due to scarce resources, justifying the distortion of the data.

One of the biggest issues with uncertainty and human error was working with the Agricultural Landuse Data from Washington's Department of Agriculture. The crop data consisted of over 190,000 objects and did not include the crop type data we needed to isolate for wheat, barley, and corn. We needed to join the feature table of crop data after we isolated our selection of cereal grains to prevent ArcGIS from crashing either during the join or querying selections for our crops. Multiple times when a join was attempted and successful, the results of queries were inaccurate in finding only the data we needed. Instead, the query would include crops like produce, tree farms, and fishery information. This became a common problem in finishing map three, because once our process yielded accurate results in finding wheat, barley, and corn, the team became concerned about possible omittance of crop plots based on misrepresented polygons in the dataset. In the end we were successful at creating layers from selections that only included the variables and crops we desired, but our data still ran the risk of possibly omitting certain plots that may have been wrongly reported in the crop data table or shapefile.

With four people working on the same maps, it runs the risk of operational errors, as all have their own biases on how to select the data to model (i.e. the islands or showing all roads or just major roads in Washington State), and even aesthetic parts of the map such as line thickness, or layer transparency.

Further Research/recommendations

Since our project consists of combination of multiple factors such as mean annual temperature, mean annual precipitation, and soil pH, it would be better to perform a multicriteria evaluation for analyses. Not only can we assign our criteria scores into more simplified means such as 0-1, we can also weight the importance of each factor based on its significance. For example, in wheat growth, soil pH may play a more major role than temperature. However, in our analysis, all factors are viewed equally. Through multicriteria evaluation, each category of factors can be weighed accordingly for a more accurate analysis. Also taking slope of the landscape into consideration would help find suitable areas for farming whereas many of our viable potential “corn fields” could rest on a steep slope making farming almost impossible.

Also, we could construct our own metadata to document the transformations from the original data source, universal language of our analysis, and possible errors made along the way.

Based on the time constraint of the project, we have decided to download datasets from online sources such as US Department of the Interior Bureau of Land Management, Washington State Department of Natural Resources etc. Although they are reliable sources of data, for future projects, if those data are not available, we might need to obtain our own data by surveying and other techniques. Potential datasets needed required registration or membership to the specific site causing our group to consider how we collect the data.

From the online sources, we were able to successfully obtain data such as precipitation, soil pH, temperature; however, those are not all the factors that can affect crop growth. For future projects, we could also obtain data such as soil temperature, growing degree days, soil nutrients, frost free days, slope, and other environmental factors that affect crop growth.

In conclusion, our analysis suggests that there is indeed potential for agricultural expansion in Washington State with regard to its top 3 cereal grains: wheat, corn and barley. However, under natural environmental conditions the expansion potential for wheat and barley is relatively insignificant. For wheat a further 43,807 acres could be brought under production, only 0.1% of Washington State area and for barley a further 151, 242 acres, only 0.33% of Washington State area. However, l for corn a further 7135091 acres could be brought under production, this equates to 15.63% of Washington State area. This is a significant area of land and subsequently it would produce a significant quantity of corn. However, our analysis is based on natural environmental conditions and it is clear that most current wheat and barley growth occurs in areas that are not naturally environmentally viable, due to artificial fertilizer, irrigation and soil amendment. Therefore, for a more realistic assessment of agricultural expansion potential perhaps a wider range of parameters need to be taken into account, including other factors that limit plant growth and factors that can artificially be used to enhance plant growth.

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