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Suitability for Global Maize Production: A Methodology Based on Spatial Analysis

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Abstract

A methodology based on spatial analysis is proposed to investigate suitability of crop, and then applied to analyzing the suitability for global maize production. The suitable and unsuitable maize cultivated regions are given based on the analysis, and maize cultivated regions sensitive to economic incentive is also illustrated and discussed.

Key words: crop suitability, maize production, spatial analysis, agricultural trade

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Introduction

Crop is usually expected to grow in suitable regions. However, it is not always true to each country or region due to current trade protection and subsidiary policy. In the places where crop is under high levels of protection and subsidies, high price would induce farmers extending crop production to unsuitable regions. Once the protection and subsidies are reduced or removed, such procedure is expected to be conducted conversely. That is, the crop area presently cultivated will diminish to such a point that farmers are willing to accept at lower price given current productive technology as well as demand for the crop. Alternatives may come in and substitute for the present ones in these regions.

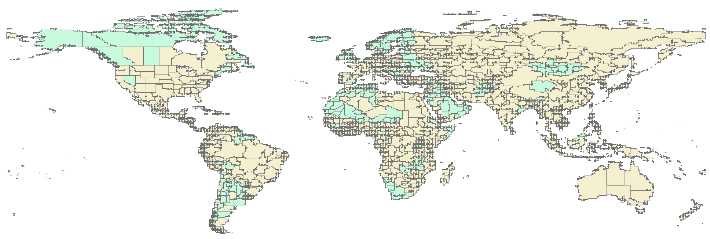
Study of distribution of crop production under a changed economic incentive depends on analysis of crop suitability. Crop simulation model is extensively employed "to evaluate the potential impact of climate changes on shifting in production and growing regions of different crops" (Bowen and Hollinger, 2004). As for crop suitability at global level, a similar model AEZ (agro-ecological zones methodology) was introduced in 2002 (Fischer, Velthuizen, Shah and Nachtergaele, 2002). However, the application of simulation models is restricted by a comprehensive understanding of crop physiology together with information on climate, soil, water, nutrients and landform. For the reason, a simple model based on geographic information system (GIS) is developed, which tries to go beyond those strict conditions for model application. The model "uses readily available specific crop edaphic requirements and climate and soil information in

GIS format to evaluate the suitability of a region's conditions for a large number of crops." (Bowen and Hollinger, 2004)

As a part of efforts to the study of crop suitability, the paper tries to investigate global maize suitability for specific locations through spatial analysis which would provide approaches for finding spatial pattern of an event. For the purpose, we will employ statistic Moran's I and LISA to investigate if, for example, the distribution of maize production is random or not. By means of visualized approach, it is easy to observe cluster and outlier of an event at some specific location. This study will apply the approaches to global maize cultivated area, yield and production and find their spatial patterns with respect to the cluster and outlier, which would give some insights of crop suitability.

Data

Data for the study is from Food and Agriculture Organization of the United Nations (FAO), including both shape files and data files. Since the Europe data has no GIS information, its shape file is constructed by world map from ESRI coupled with related FAO's dbf data. The involved regional size in the dataset is called administe1. If taking US as an example, the dataset included just covers crop production for each state. The time span for dataset is from 1996 to 1998. Some of missing values are replaced by those before or after the specific year; others by their average values from FAOSTAT. Only the regions where maize growing area is larger than zero are in consideration instead of the entire regions of crop production. In the sense, maize cultivated area is just part of the regions of crop production, which is showed in figure1. In figure1, yellow part is the maize cultivated regions while blue part plus yellow part constitute the regions of crop production.



. Figure1 Maize cultivated regions against the whole regions of crop production

The quantile maps for maize cultivated area, yield and production are showed in figure2, figure3 and figure4.

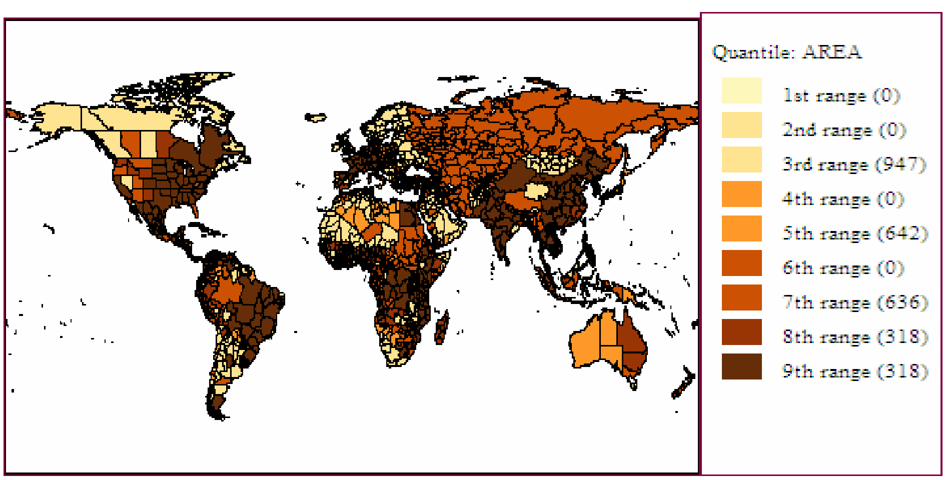


Figure2 Quantile maps for maize cultivated area

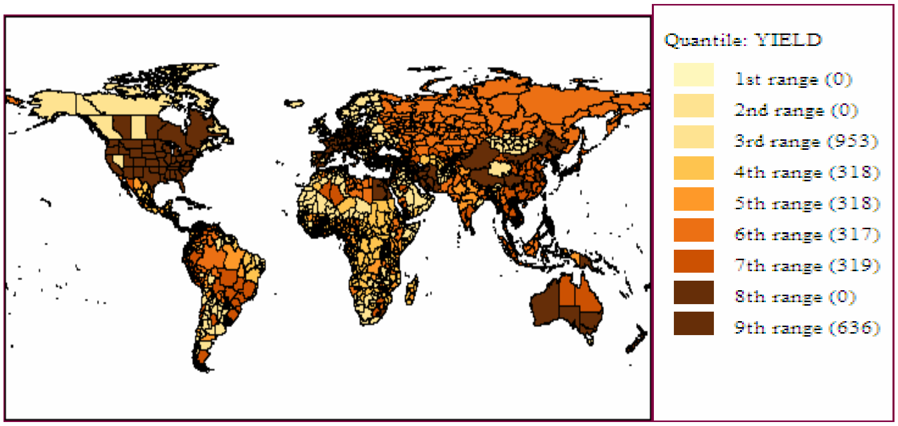


Figure3 Quantile maps for maize yield

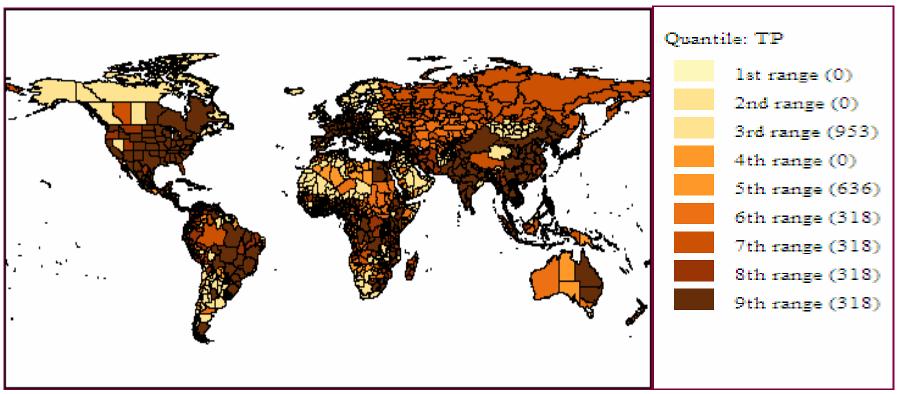


Figure4 Quantile maps for maize production

Spatial autocorrelation and test

"Spatial autocorrelation is a property that mapped data possesses whenever it exhibits an organized pattern" (Anselin). Generally, Moran's I is used as a statistic to test global spatial autocorrelation. When the test statistic is significant, there could exit global spatial autocorrelation, implying that the "values" is spatial clustering instead of homogeneity. On the other hand, LISA is used as a statistic to test local spatial autocorrelation. Similarly, the significant test statistic means local spatial autocorrelation in the regions. On the basis, clusters and outliers for an event in study can then be obtained. Since spatial weights are first needed in calculation of either Moran's I or LISA, distance-band weights, which are symmetric and have no problem of "island", is chosen in the study. The following analysis will first address the spatial pattern for maize cultivated area, yield and production on both global and local perspective, and then give the clusters and outliers for these indicators accordingly.

1. Global and Local spatial autocorrelation

Table1 Moran's I (MI) and inference

Area	MI=0.1142	MEAN=-0.0004	SD=0.0026	P-VALUE=0.0010
Yield	MI=0.5039	MEAN=-0.0004	SD=0.0027	P-VALUE=0.0010
Production	MI=0.1448	MEAN=-0.0005	SD=0.0025	P-VALUE=0.0010

Moran's I and inferences are summarized in table1. From table 1, it can be seen that global Moran's I is significant for all of the three indicators. This implies that there are spatial autocorrelation for global maize cultivated area, yield and production. That is, they are not randomly distributed in space and there exists organized pattern. Further application of LISA also reveals this spatial pattern on the local basis. The cluster maps for the area, yield and production coupled with histograms for type distinction are illustrated in figure5, figure6 and figure7. The maps are drawn in terms of LISA values and the significant level is 5%.

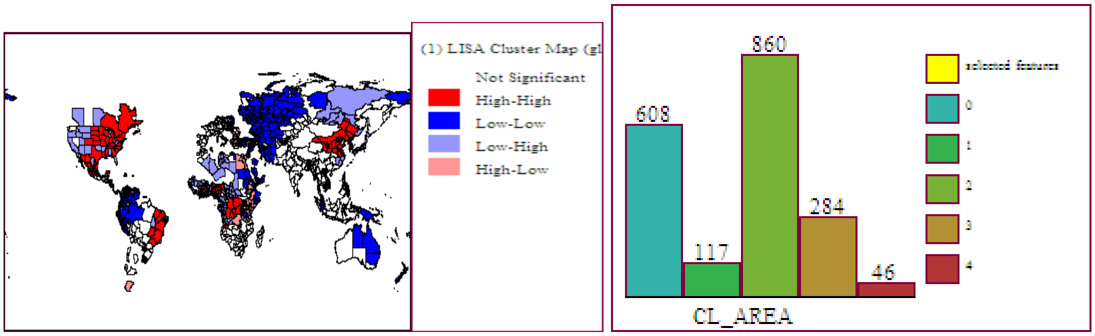


Figure5 Cluster map and histogram for area

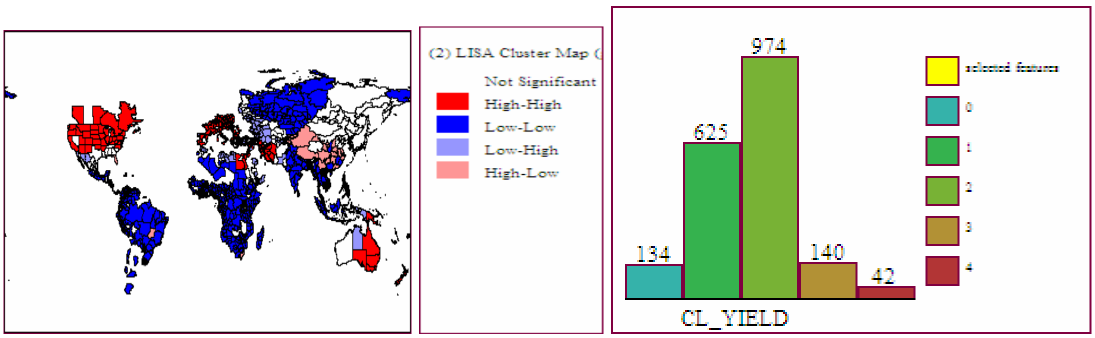


Figure6 Cluster map and histogram for yield

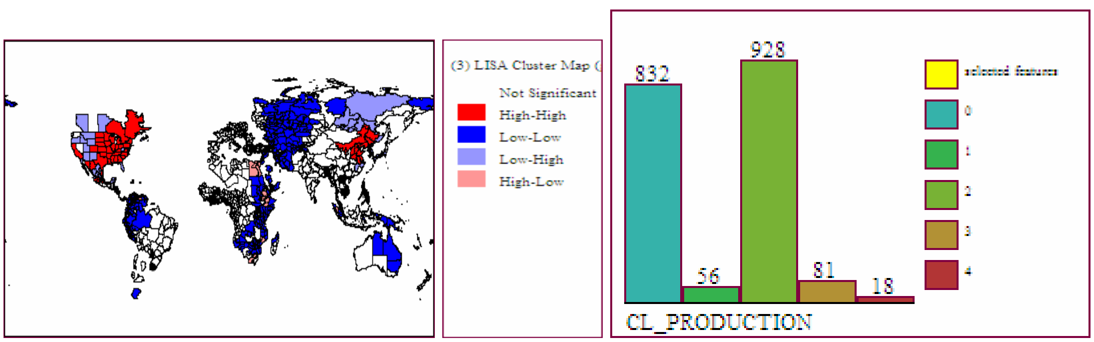


Figure7 Cluster map and histogram for production

The cluster maps (left hand) illustrate that the local spatial autocorrelation is divided into five types: not significant (white), high-high (red), low-low (blue), high-low (light red) and low-high (light blue). High-high type means that an event with high value at a location has high value neighbors. On the other hand, low-low type conversely means that a low value event at a location has low value neighbors. High-low and low-high types can be interpreted in a similar way. From figure5, fighure6 and figure7, it is easy to find the spatial pattern of maize cultivated area, yield and production. For instance, the cluster map in figure 5 illustrates that the main maize cultivated regions in US locate in its northeastern, middle-western and southwestern regions (red part), while figure 7 shows that the regions with high maize production are gathered in the eastern, middle and southern parts of US (red part). The right hand histogram in figure 7 illustrates that 832 regions are not significant in LISA for maize production while there are 56 regions belong to high-high type regions, 928 to low-low type, 81to low-high type and 18 to high-low type respectively.

2. Cluster and outlier

The high-high and low-low locations are usually named as spatial clusters while the high-low and low-high locations are spatial outliers. The clusters and outliers for maize cultivated area, yield and production in US are given in table2, table3, and table4.

The clusters and outliers for global maize cultivated area, yield and production are available upon request.

Table 2 high-high type spatial cluster for area, yield and production (US)

area		yield		production	
Region	**country**	**region**	**country**	**region**	**country**
Colorado	United States of America	Arizona	United States of America	Alabama	United States of America
Georgia	United States of America	Arkansas	United States of America	Arkansas	United States of America
Illinois	United States of America	California	United States of America	California	United States of America
Indiana	United States of America	Colorado	United States of America	Colorado	United States of America
Iowa	United States of America	Delaware	United States of America	Delaware	United States of America
Kansas	United States of America	Idaho	United States of America	Georgia	United States of America
Kentucky	United States of America	Illinois	United States of America	Illinois	United States of America
Louisiana	United States of America	Indiana	United States of America	Indiana	United States of America
Maryland	United States of America	Iowa	United States of America	Iowa	United States of America
Michigan	United States of America	Kansas	United States of America	Kansas	United States of America
Minnesota	United States of America	Kentucky	United States of America	Kentucky	United States of America
Mississippi	United States of America	Maryland	United States of America	Louisiana	United States of America
Missouri	United States of America	Michigan	United States of America	Maryland	United States of America
Nebraska	United States of America	Minnesota	United States of America	Michigan	United States of America
New York	United States of America	Missouri	United States of America	Minnesota	United States of America
North Carolina	United States of America	Montana	United States of America	Mississippi	United States of America
North Dakota	United States of America	Nebraska	United States of America	Missouri	United States of America
Ohio	United States of America	New Jersey	United States of America	Nebraska	United States of America
Pennsylvania	United States of America	New Mexico	United States of America	New York	United States of America
South Carolina	United States of America	New York	United States of America	North Carolina	United States of America
South Dakota	United States of America	North Carolina	United States of America	North Dakota	United States of America
Tennessee	United States of America	North Dakota	United States of America	Ohio	United States of America
Texas	United States of America	Ohio	United States of America	Oklahoma	United States of America
Virginia	United States of America	Oklahoma	United States of America	Pennsylvania	United States of America
Wisconsin	United States of America	Oregon	United States of America	South Carolina	United States of America
		Pennsylvania	United States of America	South Dakota	United States of America
		South Dakota	United States of America	Tennessee	United States of America
		Utah	United States of America	Texas	United States of America
		Virginia	United States of America	Virginia	United States of America
		Washington	United States of America	Wisconsin	United States of America
		West Virginia	United States of America		
		Wisconsin	United States of America		
		Wyoming	United States of America		

Table3 low-high type spatial outlier for area, yield and production(US)

area		yield		production	
Region	**country**	**Region**	**country**	**region**	**country**
Alabama	United States of America			Arizona	United States of America
Arizona	United States of America			Florida	United States of America
Arkansas	United States of America			Idaho	United States of America
California	United States of America			Montana	United States of America
Delaware	United States of America			New Jersey	United States of America
Florida	United States of America			New Mexico	United States of America
Idaho	United States of America			Oregon	United States of America
Montana	United States of America			Utah	United States of America
New Jersey	United States of America			West Virginia	United States of America
New Mexico	United States of America			Wyoming	United States of America
Oklahoma	United States of America				
Oregon	United States of America				
Utah	United States of America				
West Virginia	United States of America				
Wyoming	United States of America				

Table4 high-low type spatial outlier for area, yield and production (US)

area		yield		production	
region	**country**	**region**	**country**	**region**	**country**
		Florida	United States of America		

Suitability for maize

The spatial pattern of maize production is determined by environmental factors, supply and demand, technology, as well as trade barrier. The relationship between these factors is listed in table 5. From table 5, we can see that proper environment is positive to both yield and area while other factors are positive to either of them. For instance, in some middle-east regions, although high cost technologic inputs would induce high yield, it is not eligible to large area of maize production. On the other hand, given maize demand, protection and subsidies could result in large cultivated area instead of high yield, while rise of the demand would lead to expansion of cultivated area to increase maize supply given the technology. In the sense, we can say that the suitable regions for maize production must satisfy both high yield and large area while unsuitable region means low yield coupled with small area. In addition, the regions with large cultivated area but out of the suitable regions would be sensitive to economic incentive. For instance, low price due to either less protection or decrease of demand would lower the maize cultivated area in these regions. However, with the increase of technological inputs, the regions are expected to become suitable ones.

Table 5 Determinants of Spatial Pattern for Maize Production

	Yield	Area
Environment	+	+
Technologic Input	+	
Protection and Subsidies		+
Demand		+

The most suitable maize cultivated regions, unsuitable maize cultivated regions, and the maize cultivated regions sensitive to economic incentive are listed in table 6, table 7, table 8 and table 9. Table 6 shows that maize production is located in the most suitable regions, which are marked by the high-high type of area together with the high-high type of yield. The unsuitable maize cultivated regions are those with both low-low type of area and yield, which is illustrated in table 7 and table 8. Maize cultivated regions that are sensitive to economic incentive are those that lie out of the most suitable maize cultivated regions but with the high-high type of cultivated area (table 9).

Table 6 The Most Suitable Maize Cultivated Regions

State/Province	Country
Colorado	United States of America
Illinois	United States of America
Indiana	United States of America
Iowa	United States of America
Kansas	United States of America
Kentucky	United States of America
Maryland	United States of America
Michigan	United States of America
Minnesota	United States of America
Missouri	United States of America
Nebraska	United States of America
New York	United States of America
North Carolina	United States of America
North Dakota	United States of America
Ohio	United States of America
Pennsylvania	United States of America
South Dakota	United States of America
Virginia	United States of America
Wisconsin	United States of America
Ontario	Canada
Quebec	Canada

Table 7 Unsuitable Maize Cultivated Regions (Part I)

State/Province	Country	State/Province	Country
Ali Sabieh	Djibouti	Kokchetav	Kazakhstan
Dikhil	Djibouti	Karaganda	Kazakhstan
Djibouti	Djibouti	Kustanay	Kazakhstan
Tadjourah	Djibouti	North Kazakhstan	Kazakhstan
Tajiourah	Djibouti	Pavlodar	Kazakhstan
Bakool	Somalia	Turgay	Kazakhstan
Bay	Somalia	Tselinograd	Kazakhstan
Gado	Somalia	Arkhangel'skaya obla	Russia
Hiiran	Somalia	Respublika Bashkorto	Russia
J. Hoose	Somalia	Chelyabinskaya oblas	Russia
Sh. Hoose	Somalia	Chukotskiy avtonomny	Russia
Central3	Sudan	Chuvashskaya Respubl	Russia
Khartoum	Sudan	Evenkiyskiy avtonomn	Russia
Northern3	Sudan	Ivanovskaya oblast'	Russia
Dodoma	Tanzania, United Rep of	Khanty-Mansiyskiy av	Russia
Kigoma	Tanzania, United Rep of	Komi-Permyatskiy avt	Russia
Mara	Tanzania, United Rep of	Respublika Komi	Russia
Singida	Tanzania, United Rep of	Kirovskaya oblast'	Russia
Tabora	Tanzania, United Rep of	Krasnodarskiy kray	Russia
Iganga	Uganda	Kostromskaya oblast'	Russia
Jinja	Uganda	Kurganskaya oblast'	Russia
Kalangala	Uganda	Respublika Mordoviya	Russia
Kamuli	Uganda	Respublika Mariy-El	Russia
Kapchorwa	Uganda	Murmanskaya oblast'	Russia
Kumi	Uganda	Nenetskiy avtonomnyy	Russia
Lira	Uganda	Novosibirskaya oblas	Russia
Mbale	Uganda	Nizhegorodskaya obla	Russia
Moroto	Uganda	Omskaya oblast'	Russia
Mukono	Uganda	Orenburgskaya oblast	Russia
Pallisa	Uganda	Permskaya oblast'	Russia
Soroti	Uganda	Samarskaya oblast'	Russia
Tororo	Uganda	Sverdlovskaya oblast	Russia
Afar	Ethiopia	Tomskaya oblast'	Russia
Benshangul	Ethiopia	Respublika Tatarstan	Russia
Dire Dawa	Ethiopia	Tyumenskaya oblast'	Russia
Harari	Ethiopia	Udmurtskaya Respubli	Russia
Somali	Ethiopia	Ul'yanovskaya oblast	Russia
Kedah	Malaysia	Volgogradskaya oblas	Russia
Kelantan	Malaysia	Vladimirskaya oblast	Russia
Melaka	Malaysia	Yamalo-Nenetskiy avt	Russia
Perak	Malaysia	Yaroslavskaya oblast	Russia
Perlis	Malaysia	Aceh	Indonesia
Pulau Pinang	Malaysia	Bengkulu	Indonesia
Selangor	Malaysia	Riau	Indonesia
		West Sumatera	Indonesia

Table 8 Unsuitable Maize Cultivated Regions (Part II)

State/Province	Country	State/Province	Country	State/Province	Country
Amazonas	Venezuela	Antioquia	Colombia	Azuay	Ecuador
Anzoategui	Venezuela	Arauca	Colombia	Canar	Ecuador
Apure	Venezuela	Atlantico	Colombia	Carchi	Ecuador
Aragua	Venezuela	Boyaca	Colombia	Chimborazo	Ecuador
Barinas	Venezuela	Caldas	Colombia	Cotopaxi	Ecuador
Bolivar	Venezuela	Caqueta	Colombia	Imbabura	Ecuador
Carabobo	Venezuela	Casanare	Colombia	Loja	Ecuador
Cojedes	Venezuela	Cauca	Colombia	Morona Santiago	Ecuador
Delta Amacuro	Venezuela	Cesar	Colombia	Napo	Ecuador
Distrito Federal	Venezuela	Choco	Colombia	Pichincha	Ecuador
Falcon	Venezuela	Cundinamarca	Colombia	Sucumbios	Ecuador
Lara	Venezuela	Guainia	Colombia	Tungurahua	Ecuador
Merida	Venezuela	La Guajira	Colombia	Aguada	Puerto Rico
Miranda	Venezuela	Guaviare	Colombia	Aibonito	Puerto Rico
Monagas	Venezuela	Huila	Colombia	Anasco	Puerto Rico
Nueva Esparta	Venezuela	Magdalena	Colombia	Barranquitas	Puerto Rico
Sucre	Venezuela	Meta	Colombia	Caguas	Puerto Rico
Tachira	Venezuela	Narino	Colombia	Canovanas	Puerto Rico
Trujillo	Venezuela	Norte de Santander	Colombia	Cayey	Puerto Rico
Yaracuy	Venezuela	Putumayo	Colombia	Cidra	Puerto Rico
Zulia	Venezuela	Quindio	Colombia	Coamo	Puerto Rico
Ancash	Peru	Risaralda	Colombia	Comerio	Puerto Rico
Apurimac	Peru	Santander	Colombia	Corozal	Puerto Rico
Arequipa	Peru	Tolima	Colombia	Guayanilla	Puerto Rico
Ayacucho	Peru	Valle del Cauca	Colombia	Gurabo	Puerto Rico
Cajamarca	Peru	Vichada	Colombia	Hatillo	Puerto Rico
Cusco	Peru	Chiriqui	Panama	Isabela	Puerto Rico
Huancavelica	Peru	Cocle	Panama	Luquillo	Puerto Rico
Huanuco	Peru	Colon	Panama	Orocovis	Puerto Rico
Ica	Peru	Darien	Panama	Patillas	Puerto Rico
Junin	Peru	Herrera	Panama	Sabana Grande	Puerto Rico
La Libertad	Peru	Los Santos	Panama	Salinas	Puerto Rico
Lambayeque	Peru	Panama	Panama	San German	Puerto Rico
Lima	Peru	Veraguas	Panama	San Lorenzo	Puerto Rico
Loreto	Peru	Artibonite	Haiti	San Sebastian	Puerto Rico
Pasco	Peru	Centre	Haiti	Toa Alta	Puerto Rico
Piura	Peru	Nord	Haiti	Villalba	Puerto Rico
San Martin	Peru	Nord-Est	Haiti	Yauco	Puerto Rico
Tumbes	Peru	Nord-Ouest	Haiti	Florida	Uruguay
Ucayali	Peru	Ouest	Haiti	San Jose	Uruguay
Coronie	Suriname	Sud	Haiti		
Nickerie	Suriname	Sud-Est	Haiti		

Table 9 Maize Cultivated Regions Sensitive to Economic Incentive

State/Province	Country	State/Province	Country
Benguela	Angola	Anhui	China
Bie	Angola	Beijing	China
Huambo	Angola	Gansu	China
Ashanti	Ghana	Hebei	China
Eastern	Ghana	Heilongjiang	China
Northern	Ghana	Henan	China
Sikasso	Mali	Jiangsu	China
Abia	Nigeria	Jilin	China
Adamwara	Nigeria	Liaoning	China
Akwalbom	Nigeria	Inner Mongolia	China
Anambra	Nigeria	Ningxia	China
Bauchi	Nigeria	Shaanxi	China
Benue	Nigeria	Shandong	China
Borno	Nigeria	Shanxi	China
Cross River	Nigeria	Tianjin	China
Delta	Nigeria	Campeche	Mexico
Edo	Nigeria	Chihuahua	Mexico
Enugu	Nigeria	Durango	Mexico
FCT	Nigeria	Guanajuato	Mexico
Imo	Nigeria	Hidalgo	Mexico
Jigawa	Nigeria	Jalisco	Mexico
Kaduna	Nigeria	Mexico	Mexico
Kano	Nigeria	Michoacan	Mexico
Katsina	Nigeria	Nayarit	Mexico
Kebbi	Nigeria	Nuevo Leon	Mexico
Kogi	Nigeria	Puebla	Mexico
Kwara	Nigeria	Queretaro	Mexico
Lagos	Nigeria	San Luis Potosi	Mexico
Niger	Nigeria	Sinaloa	Mexico
Ogun	Nigeria	Sonora	Mexico
Ondo	Nigeria	Tabasco	Mexico
Osun	Nigeria	Tamaulipas	Mexico
Oyo	Nigeria	Tlaxcala	Mexico
Plateau	Nigeria	Veracruz	Mexico
Rivers	Nigeria	Yucatan	Mexico
Sokoto	Nigeria	Zacatecas	Mexico
Taraba	Nigeria	Bahia	Brasil
Yobe	Nigeria	Ceara	Brasil
Maritime	Togo	Goias	Brasil
Bandundu	Congo, Dem Republic of	Maranhao	Brasil
Equateur	Congo, Dem Republic of	Minas Gerais	Brasil
Haut-Zaire	Congo, Dem Republic of	Pernambuco	Brasil
Kasai-Occidental	Congo, Dem Republic of	Piaui	Brasil
Kasai-Oriental	Congo, Dem Republic of	Sao Paulo	Brasil
Kivu	Congo, Dem Republic of	Georgia	United States of America
		Louisiana	United States of America
		Mississippi	United States of America
		South Carolina	United States of America
		Tennessee	United States of America
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