Future Global Soybean Yield Projections

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Abstract

This paper introduces the relationships between climate conditions and global scale soybean yields and their future projections until 2050. Using a combination of historical datasets and climate model projections, yield responses to temperature and precipitation change were discussed together with input of fertilizer. Future climate projection is based on downscale dataset from IPCC, A1 scenario. Datasets used in this study include spatial information but not yield data. To improve the accuracy of estimation, the specific vegetation types were used to obtain climate conditions on crop area. The relationships between soybean yield and climate conditions on crop area were conducted for soybean producing countries and future global soybean yield until 2050 are discussed.

Keywords: Yield, Accumulated temperature and precipitation, Cropping calendar, Downscaling

1. Introduction

Economic development and population increase will result in shortage of food (Matsumura, 2011). Climate change influences crop yield and casts a shadow on food production. In 2010 summer, India and Nepal suffered from heavy rain, Italy was more humid and the USA was hot summer. Russia announced that crop production in 2010 went down 26 % from previous year and stopped exporting crop due to extreme climate event. These facts suggest that it is important to estimate the impact of changes in climatic condition on major crop yield such as rice, wheat, soybean, and maize. Table 1 suggests the top 5 major crop producing countries in the world. This paper introduces the development of methodology and the relationships between yield and climate conditions on crop for soybean producing countries.

Rice plays a crucial role in the supporting continued global population growth. World rice production in 2007 was approximately 645 million tons, with Asian farmers producing 90% and China and India producing 50% of the global rice supply (Kawashima, 2008). Animal nutritionists have observed that combining one part soybean meal with four parts grain dramatically boosts the efficiency of livestock and poultry; this converted grain into animal protein. Soybean occupies more U.S cropland than wheat (Lester R. Brown, 2009).

There are several researches related to climate conditions and crop yield. Data on national crop yields for 1961–2002 in the ten leading producers of wheat, rice and maize were combined with datasets on climate and crop locations to evaluate the empirical relationships between average temperature and the difference between daily maximum and minimum temperature and crop yields (David B, 2007).

The author's previous study analyzed the relationships between country based precipitation and crop yield (Matsumura, 2010). As a preliminary research, the author conducted the relationships between crop yield, precipitation and temperature for major top 5 crop producing countries using country averaged datasets. The multiple correlation coefficients were 0.245 for Maize (USA), 0.328 for Soybean (USA), 0.16 for Wheat (USA) and 0.185 for Rice (China). The correlation coefficient value is not so high. To improve the accuracy of estimation, the specific vegetation types were used to obtain climate conditions on crop area.

Figure 1 shows the comparison of country averaged precipitation and precipitation on crop area in USA. The comparison shows that the fluctuations of precipitation on crop area is less small compared with country averaged precipitation. This tendency can be seen in other countries.

2. Datasets

The datasets used to obtain the relationships between climate conditions and crop yield are introduced in 2.1 and future projections of down scaled climate conditions including data processing methodologies are introduced in 2.2. Datasets used in this study included spatial information but not yield data.

2.1 Combining data sets

Datasets with spatial information such as temperature, precipitation, vegetation, and cropping calendar were used in this study and country based major crop yields of wheat, soybean, rice, and maize were obtained from Food and Agricultural Organization (FAO-STAT, 2010). Crop yield dataset covers 236 countries and 5 areas such as Africa, Americas, Asia, Europe, and Oceania but not with spatial information. Crop yield dataset and fertilizer data set are provided b FAO and covers from 1961 to 2009, from 1961 to 2002 respectively.

The vegetation data-set developed by a global mapping project (GSI, 2008) is used to highlight the vegetation type especially sparse vegetation, cropland, paddy field, and cropland/other vegetation mosaic. The grid size is 30 seconds by 30 seconds (often referred to as 1-km spatial resolution).

Monthly average temperature and precipitation datasets from January 1961 to December 2006 are obtained from the Climatic Research Unit, University of East Anglia (CRU, 2010) shown in Figure 4. Using vegetation dataset, temperature and precipitation on crop area are extracted and making use of boundary dataset (ESRI, 2008), country averaged precipitation and temperatures on crop area were obtained.

Multiplying highlighted crop area by temperature and precipitation datasets, temperature and precipitation on crop land can be extracted. Using of country boundary dataset (ESRI, 2008), precipitation and temperature on crop land are recalculated as an average value in for 186 countries

Digitizing and geo-referencing the existing observations on crop planting and harvesting dates yielded the Cropping Calendar datasets (Cropping Calendar, 2009). The cropping calendar consists of 5 components: planting, vegetating, heading, filling, and harvesting. On the basis of the cropping calendar, the life cycle of major crops, including the five components in each country, is obtained. Overall conceptual framework to generate datasets for estimation is shown in Figure 6.

2.2 Developing downscaled projection data

The outputs of Global Climate Model (GCM) are quoted in IPCC, AR4 report and used for future global scale soybean projection. The outputs are based on IPCC SRES scenarios A1. To apply the future results for estimated equation listed in Table 2, it is required to downscale the future projection outputs. In another world, the grid size of GCM is 100 km and downscaled projection data will be required. Each GCM uses a scenario defined “20C3M” (20th Century Climate Coupled Model) to verify the reappearance. The parameters in each model are different and bias should be extracted to obtain downscaled projection. Following procedures are conducted to obtain downscaled monthly average temperature and precipitation.

(STEP1) The average temperature and precipitation datasets of CRU TS 2.10 in each month from 1971 to 2000 are calculated.

(STEP2) The GCM output’s average from 1971 to 2000 is calculated and imposed in 0.5 degree spatial dataset.

(STEP3) The GCM outputs based on SRES scenarios in 2010, 2020, 2030, 2040 and 2050 are obtained and imposed in 0.5 degree spatial dataset. (STEP4) The ratio of precipitation and temperature processed in STEP2 and STEP3 are calculated. The relationship “Kelvin=Celsius+273.15” is used. Bilinear Interpolation methodology is used. The value in Grid T (x, y) is calculated by nearby 4 points following equation.

$$f(x,y) = \frac{Q_{11}(x_2 - x)(y_2 - y) + Q_{12}(x - x_1)(y_2 - y) + Q_{21}(x_2 - x)(y - y_1) + Q_{22}(x - x_1)(y - y_1)}{(x_2 - x_1)(y_2 - y_1)}$$

The bilinear interpolation methodology, original GCM outputs, imposed values are shown in Figure 7. The example of imposed datasets is shown in Figure 8. The figure expresses the average monthly temperature in June from 2041 to 2050.

3. Analysis

3.1 Multiple regression analysis

Country based major crop yields of wheat, soybean, rice, and maize were obtained from Food and Multiplying highlighted crop area by temperature and precipitation datasets, temperature and precipitation on crop land can be extracted. Using of country boundary dataset (ESRI, 2008). Precipitation and temperature on crop land are recalculated as a country based average value. Aggregating temperature and precipitation data based on cropping calendar, the aggregated precipitation and temperature datasets are obtained. Figure 9 shows the structure of a generated dataset in China. The generated datasets cover 186 countries and four major crops. Each country covers four major crop yield, monthly temperature, precipitation, fertilizer per area and cropping calendar information. Cropping calendar in includes plant_start, plant_range, plant_end, harvest_start, harvest_range, harvest_end, total days with spatial information. Using of country boundary dataset, cropping calendar information is also recalculated as a country based average value. If plant starts in July and harvest ends in September, temperature and precipitation datasets are aggregated from July to September. If plant starts in October and harvest ends in March, temperature and precipitation datasets are aggregated from October to next year's March.

The relationships among soybean yield, aggregated temperature, aggregated precipitation, fertilizer per agricultural area were obtained by using multiple regression analysis. Case A used temperature and precipitation. Case B used temperature, precipitation, and fertilizer.

Case A Y=f(Tsum, Psum)

Case B Y=f(Tsum, Psum, F)

f: function, Y: (Yield), F: (Fertilizer), Tsum: Accumulated temperature, Psum: Accumulated precipitation

The multiple regression analysis for soybean yield is conducted for 186 and outputs are listed in Table 2.

Applying actual monthly temperature and precipitation dataset for obtained equation listed in Table 2, the actual value and calculated value of yield in each country are then obtained. Figure 10 shows the soybean yield of actual, calculated value in case A and case B in USA as an example.

In general, as for crop yield, if temperature and precipitation increase, crop yield is expected to increase. Table 2 shows the opposite result in some countries.

In Chile, Mexico, Ethiopia, Iraq, Russia, Croatia, Serbia & Montenegro, Greece, Austria, Czech Republic, Slovakia, Romania, Ukraine, Kyrgyzstan, Laos, Malaysia, Gabon, Madagascar, the temperature increase results in soybean crop yield decrease.

In Chile, Peru, Mexico, Honduras, Liberia, Spain, Ethiopia, Uganda, Kazakhstan, Cameroon, Benin, Croatia, Italy, Greece, Turkey, Slovakia, Belgium, France, Sri Lanka, Nepal, China, Japan, North Korea, South Korea, Cambodia, Laos, Malaysia, Gabon, Madagascar, the precipitation increase results in soybean crop yield decrease.

IPCC reports that precipitation changes occur more spatially and seasonally in the eastern parts of North and South America, northern Europe, and northern and central Asia become significantly wet. However, the Sahel, the Mediterranean, southern Africa, and parts of southern Asia become drier (IPCC, 2007) Attention should be paid to some places where the temperature drops below zero, the frost formed provides water for the soil. For those countries where infrastructures are not well equipped, temperature plays an important role for providing water on crop.

3.2 Future projections of global soybean yield

Future monthly temperature and precipitation datasets are obtained from 2010 to 2050 by every 10 years. Using same methodology mentioned above, future monthly temperature and precipitation are applied for obtained equations in Case A. As for using future projections of fertilizer is an issue of concern. Adjusting actual value in 2009 and calculated value in 2010 in same value and global scale future projections of soybean yields are obtained. "+" suggests that soybean yield will be increased and "-" suggests that soybean yield will be decreased.

4. Conclusion

The relationships among yield and climate conditions on crop area were conducted for soybean producing countries and the influence of temperature, precipitation, and fertilizer were obtained. It is well known that temperature and precipitation increase result in increase of yield.

There are several countries that conflicts with well known fact. There are some countries where temperature increase results in decrease of yield. Also, attention should be paid to some places where the temperature drops below zero, the frost formed provides water for the soil. For those countries where infrastructures are not well equipped, temperature plays an important role for providing water on crop.

According to William C. (2007), country-level climate projections were conducted, and a consensus that warming would continue in a similar pattern up to the 2080s was obtained in the general circulation model (GCM) climate projections.

IPCC reports that precipitation changes occur more spatially and seasonally in the eastern parts of North and South America, northern Europe, and northern and central Asia become significantly wet. However, the Sahel, the Mediterranean, southern Africa, and parts of southern Asia become drier (IPCC, 2007).

Those data used in this study have spatial information but yield data. If yield information at targeted area can be obtained, the relationships among yield, temperature and precipitation can be obtained at targeted area. The authors are working on developing database which can provide time series temperature and precipitation data at targeted area.

The authors are working on estimating the relationships for other major crops such as wheat, rice, and maize and future projections of major crop yield. In this paper, linear multiple regression analysis is simply used in this paper, but for the future challenges, non linear multiple regression analysis is expected to conduct.

The methodology introduce in this paper can be useful educational tools and authors are planning to organize workshop for foreign students from all over the world.

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Table 1. Top 5 Major Crop Producing Countries (Unit: tones)

Year 2009	Maize	Soy beans	
USA	333,010,910	USA	91,417,300
China	163,118,097	Brazil	56,960,732
Brazil	51,232,447	Argentina	30,993,379
Mexico	20,202,600	China	14,500,141
Indonesia	17,629,740	India	10,217,000
Rice, paddy		Wheat	
China	197,257,175	China	114,950,296
India	131,274,000	India	80,680,000
Indonesia	64,398,890	Russian Federation	61,739,750
Bangladesh	45,075,000	USA	60,314,290
Viet Nam	38,895,500	France	38,324,700

Table 2. The results of world soybean producing countries in Case A and Case B

	Constant	Regression Coefficient (Temperature)	Regression Coefficient (Precipitation)	Multiple Correlation Coefficient		Constant	Regression Coefficient (Temperature)	Regression Coefficient (Precipitation)	Regression Coefficient (Fertilizer)	Multiple Correlation Coefficient
11 Argentina	-87665.794	311.279	8.450	0.447	Argentina	-61553.768	234.383	3.923	182.683	
	-2.230	2.447	2.409			-1.923	2.271	1.219	3.947	
13 Brazil	-186039.311	336.885	2.803	0.642	Brazil	-6555.097	28.881	-0.176	70.913	
t-value	-4.967	5.219	1.079		t-value	-0.254	0.649	-0.128	10.339	
14 Chile	16351.375	-66.504	-0.324	0.140	Chile	15699.031	-60.404	-0.393	1.033	
t-value	1.759	-0.605	-0.055		t-value	1.493	-0.503	-0.065	0.148	
15 Ecuador	9707.026	15.631	0.249	0.104	Ecuador	-1476.824	47.939	0.052	11.945	
t-value	0.464	0.223	0.456		t-value	-0.069	0.668	0.098	1.817	
16 Paraguay	-54032.511	115.386	3.132	0.335	Paraguay	-24610.549	65.423	1.698	169.662	
t-value	-1.188	1.443	1.903		t-value	-0.549	0.830	1.009	2.494	
17 Peru	-7786.277	882.461	-28.718	0.334	Peru	2074.312	506.499	-31.311	16.518	
t-value	-0.329	1.249	-2.007		t-value	0.081	0.652	-2.113	1.610	
18 Uruguay	-39569.686	78.431	1.524	0.318	Uruguay	14688.657	-11.139	0.076	36.332	
t-value	-1.151	1.433	1.788		t-value	0.522	-0.248	0.105	4.716	
19 Canada	18582.334	347.681	104.963	0.434	Canada	12784.683	173.444	79.836	35.443	
t-value	4.169	3.052	2.137		t-value	2.920	1.546	1.697	3.810	
20 Guatemala	-199607.234	151.361	0.366	0.601	Guatemala	-74172.592	231.381	5.650	52.586	
t-value	-2.950	3.199	0.215		t-value	-1.026	1.031	1.377	3.215	
21 Mexico	32754.205	-52.261	-0.954	0.145	Mexico	24220.798	-16.545	-0.109	-11.299	
t-value	2.098	-0.939	-0.280		t-value	1.404	-0.265	-0.032	-2.227	
29 Colombia	-35406.969	145.096	2.105	0.364	Colombia	-11472.516	71.588	1.445	9.398	
t-value	-1.525	2.265	1.982		t-value	-0.638	1.442	1.694	6.006	
32 El Salvador	-86820.794	232.492	6.481	0.575	El Salvador	-39376.187	139.155	6.246	-22.985	
t-value	-2.851	3.309	2.141		t-value	-1.202	1.888	2.218	-2.991	
33 Honduras	19544.959	0.813	-0.007	0.009	Honduras	51015.787	-71.716	0.098	-1.583	
t-value	0.609	0.026	-0.009		t-value	2.563	-1.538	0.092	-0.618	
34 Nicaragua	-41715.698	85.619	2.377	0.527	Nicaragua	-16208.814	53.091	1.321	-17.096	
t-value	-1.635	2.100	2.942		t-value	-0.696	1.447	1.742	-3.179	
45 Ghana	-53527.639	111.634	3.708	0.379	Ghana	-25954.398	65.418	2.089	-25.562	
t-value	-1.950	2.288	1.510		t-value	-0.851	1.211	0.820	-1.296	
46 Liberia	-9958.041	63.314	-0.836	0.679	Liberia	-6560.711	49.929	-1.213	-4.026	
t-value	-3.229	4.714	-3.746		t-value	-1.532	2.663	-5.469	-0.893	
47 Morocco	4532.387	11.271	3.975	0.238	sorocco	20032.340	-4.206	5.817	-119.177	
t-value	0.216	0.132	0.966		t-value	0.894	-0.051	1.411	-1.592	
49 Spain	4128.106	51.398	-1.146	0.292	Spain	14552.236	-15.104	0.445	15.824	
t-value	0.417	1.751	-0.757		t-value	1.681	-0.506	0.344	3.821	
54 Mali	11504.415	26.995	7.075	0.422	Mali	17441.733	-8.995	7.720	-2.202	
t-value	2.348	0.905	2.055		t-value	3.718	-0.314	2.560	-1.034	
61 Ethiopia	30006.758	-50.004	-1.676	0.196	Ethiopia	4307.050	12.343	-0.309	4.713	
t-value	0.519	-0.343	-0.402		t-value	0.970	1.120	-1.051	0.707	
64 Uganda	-28925.022	952.528	-5.238	0.516	Uganda	-27933.029	930.425	-4.968	-16.500	
t-value	-2.834	3.821	-0.559		t-value	-2.164	2.959	-0.506	-0.374	
65 Iraq	22903.242	-93.001	5.338	0.411	Iraq	14244.139	-11.778	7.474	-11.373	
t-value	3.185	-1.805	1.077		t-value	2.138	-0.237	1.764	-2.811	
68 Kazakhstan	15988.790	13.142	-4.460	0.166	Kazakhstan	9283.350	-5.965	3.255	-31.256	
t-value	2.210	0.495	-0.399		t-value	1.709	-0.292	0.392	-0.408	
70 Russia	-8278.435	-157.226	80.998	0.705	Russia	2926.915	29.407	23.378	5.566	
t-value	-1.576	-2.000	3.289		t-value	0.702	0.559	1.133	2.492	
74 Cameroon	-3668.043	56.657	-1.245	0.162	Caseroon	-281.028	28.669	2.531	5.163	
t-value	-0.317	0.809	-0.207		t-value	-0.019	0.317	0.350	1.205	
78 Benin	-2682.214	17.456	-0.418	0.170	Benin	-2761.349	16.013	-1.185	25.985	
t-value	-0.178	0.663	-0.187		t-value	-0.204	0.667	-0.694	2.452	
83 Nigeria	-42351.910	103.412	1.292	0.387	Nigeria	-15325.939	42.661	1.881	-12.255	
t-value	-2.406	2.612	0.607		t-value	-0.973	1.199	1.031	-2.018	
86 Albania	8179.514	9.674	0.646	0.119	Albania	7708.558	15.027	0.478	-1.259	
t-value	0.855	0.245	0.516		t-value	0.704	0.343	0.349	-0.166	
88 Croatia	32722.043	-52.610	-0.609	0.400	Croatia	31042.670	-58.967	0.539	1.285	
t-value	3.756	-1.412	-0.262		t-value	2.863	-1.350	0.199	0.065	
89 Italy	-10538.880	170.133	-4.918	0.526	Italy	-9287.439	108.048	-3.776	38.145	
t-value	-0.623	3.290	-2.106		t-value	-0.869	3.231	-2.546	7.927	
91 Serbia & Montenegro	21890.122	-50.256	3.930	0.471	Serbia & Monte	12738.072	-38.410	3.276	89.759	
t-value	1.895	-1.305	1.106		t-value	1.302	-1.344	1.031	2.845	
94 Egypt	4780.745	326.589	76.018	0.136	Egypt	1639.564	63.958	-4.514	45.936	
t-value	0.149	0.592	0.579		t-value	0.073	0.170	-0.051	6.335	
95 Georgia	-15475.614	340.794	4.460	0.375	Georgia	1514.200	40.930	10.283	-53.152	
t-value	-0.426	1.338	0.199		t-value	0.070	0.237	0.849	-1.234	
96 Greece	45614.140	-91.077	-4.885	0.426	Greece	10920.116	-35.964	0.329	39.128	
t-value	3.239	-1.189	-1.406		t-value	0.481	-0.449	0.077	1.875	
99 Turkey	26845.253	12.510	-7.027	0.179	Turkey	12678.988	-11.339	-1.825	74.888	
t-value	2.406	0.191	-1.169		t-value	1.718	-0.278	-0.479	6.417	
100 Austria	15255.895	-150.829	14.300	0.554	Austria	24487.368	-87.752	10.782	-16.259	
t-value	2.435	-1.874	1.979		t-value	2.299	-0.950	1.397	-1.317	
101 Czech Republic	14299.277	-35.588	2.744	0.450	Czech Republic	21961.381	-14.377	-2.164	-5.441	
t-value	1.559	-1.579	0.506		t-value	0.816	-0.450	-0.248	-0.137	
103 Hungary	11786.564	8.773	0.250	0.075	Hungary	13979.203	19.503	-2.766	7.685	
t-value	1.637	0.472	0.108		t-value	2.249	1.314	-1.411	1.674	
105 Slovakia	21505.174	-41.867	-2.324	0.463	Slovakia	20078.872	-36.255	-2.137	3.814	
t-value	3.693	-1.331	-0.467		t-value	1.119	-0.881	-0.338	0.055	
108 Belgium	117621.190	82.726	-8.837	0.534	Belgium	No Fertilizer Data				
t-value	3.051	0.453	-1.016		t-value					
109 France	955.961	101.079	-1.546	0.522	France	17223.846	69.629	-0.915	-12.602	
t-value	0.129	3.354	-0.955		t-value	1.468	2.047	-0.580	-1.924	
114 United States	4786.146	108.903	13.616	0.551	United States	-199.576	81.322	10.160	38.094	
t-value	1.084	3.670	2.658		t-value	-0.039	2.741	2.075	2.383	
121 Romania	8488.319	-4.730	2.656	0.167	Romania	12664.626	-7.499	0.013	-0.835	
t-value	1.634	-0.252	1.069		t-value	2.471	-0.464	0.006	-0.105	
122 Ukraine	5107.689	-7.078	3.102	0.351	Ukraine	7704.426	-5.985	1.788	-3.647	
t-value	0.991	-0.674	1.235		t-value	1.490	-0.553	0.700	-0.506	

Table 2. The results of world soybean producing countries in Case A and Case B (Continued)

	Constant	Regression Coefficient (Temperature)	Regression Coefficient (Precipitation)	Multiple Correlation Coefficient	Constant	Regression Coefficient (Temperature)	Regression Coefficient (Precipitation)	Regression Coefficient (Fertilizer)	Multiple Correlation Coefficient
123 India	-41029.737	40.794	4.907	0.522	India	5559.071	-2.827	2.377	23.872
t-value	-2.513	2.681	2.965		t-value	0.379	-0.207	1.757	5.650
126 Sri Lanka	-24270.952	44.935	-0.065	0.211	Sri Lanka	-15230.238	35.675	-0.282	-5.913
t-value	-0.915	1.304	-0.242		t-value	-0.541	0.947	-1.236	-0.986
131 Azerbaijan	2425.778	19.072	1.674	0.822	Azerbaijan	4763.291	11.096	2.112	-10.395
t-value	1.020	3.775	1.945		t-value	1.651	1.428	2.384	-1.308
132 Iran	-10187.089	291.377	20.038	0.416	Iran	4650.416	45.816	11.438	35.477
t-value	-1.126	2.937	1.428		t-value	0.601	0.502	1.024	4.402
138 Kyrgyzstan	2690.655	-179.530	5.359	0.347	Kyrgyzstan	-9655.312	-153.678	9.832	167.729
t-value	0.413	-1.159	0.281		t-value	-1.344	-1.014	0.571	2.359
139 Nepal	-15632.827	101.705	-0.074	0.602	Nepal	-5080.287	47.055	-0.054	50.502
t-value	-3.454	4.970	-0.040		t-value	-1.611	3.156	-0.051	5.383
140 Pakistan	-46588.691	135.912	6.686	0.414	Pakistan	2720.372	3.511	-2.981	28.776
t-value	-2.581	2.930	1.603		t-value	0.180	0.090	-0.890	6.240
141 Tajikistan	-222.728	6.208	0.015	0.355	Tajikistan	7.238	5.629	-0.021	-0.583
t-value	-0.506	1.251	0.059		t-value	0.019	1.302	-0.121	-2.761
145 China	7308.592	231.969	-14.616	0.720	China	11016.037	-27.135	-4.048	25.216
t-value	2.073	6.627	-2.106		t-value	6.907	-1.086	-1.254	13.306
146 Japan	16316.987	169.535	-10.333	0.599	Japan	10906.384	157.172	-8.746	6.720
t-value	5.646	4.028	-3.978		t-value	3.471	3.812	-3.439	2.870
147 North Korea	12915.428	189.433	-15.845	0.480	North Korea	10376.994	180.126	-16.372	9.504
t-value	8.605	3.108	-2.068		t-value	8.528	3.762	-2.814	5.884
148 Philippines	-50381.760	138.080	0.462	0.591	Philippines	23845.772	-38.933	-0.064	50.113
t-value	-3.863	4.568	1.403		t-value	1.767	-1.223	-0.273	6.961
149 South Korea	4036.342	217.440	-8.186	0.586	South Korea	1738.553	0.686	0.868	17.803
t-value	1.285	4.570	-2.162		t-value	1.096	0.022	0.421	10.960
150 Cambodia	-79472.114	106.348	-0.263	0.375	Cambodia	-65692.874	89.674	-0.438	297.611
t-value	-2.210	2.570	-0.165		t-value	-1.711	2.014	-0.258	1.209
151 Laos	16269.936	-11.587	-0.237	0.156	Laos	16103.325	-11.521	-0.131	-42.432
t-value	2.081	-0.924	-0.521		t-value	1.892	-0.835	-0.276	-0.673
152 Malaysia	37452.548	-114.800	-1.821	0.124	Malaysia	94934.522	-383.525	-1.928	3.369
t-value	0.468	-0.325	-0.643		t-value	0.997	-0.897	-0.683	1.105
153 Myanmar	-36802.332	64.759	0.632	0.500	Myanmar	-11352.376	25.196	0.593	61.054
t-value	-3.083	3.736	0.926		t-value	-1.183	1.777	1.223	3.792
154 Thailand	-28964.833	46.483	0.842	0.326	Thailand	19782.186	-11.669	-0.196	37.838
t-value	-1.629	2.305	0.929		t-value	2.111	-1.092	-0.397	10.710
155 Vietnam	-50561.830	94.356	0.054	0.512	Vietnam	-4514.464	13.622	0.201	31.768
t-value	-3.317	3.859	0.071		t-value	-0.726	1.346	0.700	13.608
162 Zambia	-78767.381	104.439	2.310	0.399	Zambia	-92799.871	124.599	2.409	-19.084
t-value	-2.088	2.355	1.619		t-value	-1.998	2.266	1.453	-0.922
163 Zimbabwe	-36615.942	52.644	0.447	0.191	Zimbabwe	-82197.285	88.313	0.473	99.413
t-value	-0.849	1.248	0.460		t-value	-1.636	1.797	0.472	2.863
168 South Africa	-96889.380	299.264	6.823	0.381	South Africa	-29096.335	79.023	2.535	84.776
t-value	-2.388	2.664	1.534		t-value	-0.819	0.786	0.721	5.701
174 Gabon	72389.055	-917.598	-4.145	0.568	Gabon	89819.762	-1184.714	-4.230	-2.124
t-value	3.257	-2.655	-0.735		t-value	3.198	-2.711	-0.689	-0.384
177 Madagascar	91998.071	-114.244	-1.254	0.535	Madagascar	75587.388	-86.599	-1.436	-52.618
t-value	2.618	-2.098	-2.467		t-value	1.985	-1.463	-2.685	-0.264
180 Indonesia	-132289.587	542.229	4.946	0.853	Indonesia	-25251.996	114.942	1.982	24.510
t-value	-9.848	10.250	5.153		t-value	-1.718	1.973	2.809	8.364
182 Australia	-63183.560	546.367	3.619	0.351	Australia	-52604.251	431.170	1.330	42.843
t-value	-1.901	2.397	0.233		t-value	-1.629	1.929	0.089	2.287

Table 3. Future soybean yield projections

Soybean	2009	2010	2020	2030	2040	2050	
13 Brazil	26,176	26,176	26,268	25,744	26,159	26,024	-
14 Chile	25,352	25,352	25,405	25,369	25,369	25,475	+
15 Ecuador	19,677	19,677	19,701	19,701	19,681	19,680	+
16 Paraguay	15,000	15,000	14,986	14,615	14,703	14,667	-
17 Peru	17,096	17,096	17,036	17,287	17,352	17,394	+
18 Uruguay	17,802	17,802	17,678	17,745	17,581	17,595	-
19 Canada	25,352	25,352	25,405	25,369	25,369	25,475	+
20 Guatemala	26,428	26,428	26,428	26,424	26,422	26,415	-
21 Mexico	18,600	18,600	18,610	18,606	18,596	18,616	+
29 Colombia	22,000	22,000	21,958	22,137	21,380	21,509	-
32 El Salvador	22,727	22,727	22,694	22,526	22,459	22,289	-
33 Honduras	21,333	21,333	21,335	21,333	21,333	21,333	+
49 Spain	2,166	2,166	2,172	2,177	2,155	2,172	+
61 Ethiopia	12,666	12,666	12,782	12,839	12,651	12,765	+
64 Uganda	12,000	12,000	12,040	12,041	11,998	11,966	-
65 Iraq	10,000	10,000	9,881	9,840	9,802	9,655	-
68 Kazakhstan	22,638	22,638	24,052	24,042	23,982	23,998	+
70 Russia	11,881	11,881	2,277	3,414	3,949	3,996	-
74 Cameroon	6,000	6,000	6,006	6,015	6,002	6,010	+
78 Benin	5,489	5,489	5,513	5,516	5,510	5,515	+
83 Nigeria	9,682	9,682	9,650	9,638	9,717	9,654	-
86 Albania	16,666	16,666	16,951	16,596	17,215	17,150	+
88 Croatia	25,999	25,999	25,731	26,070	25,578	25,766	-
89 Italy	34,758	34,758	32,826	33,939	30,871	31,126	-
94 Egypt	36,854	36,854	35,565	35,513	35,567	35,406	-
95 Georgia	100,000	100,000	93,820	93,129	93,569	93,876	-
96 Greece	20,000	20,000	19,511	19,838	19,531	19,455	-
99 Turkey	36,569	36,569	34,926	35,719	35,734	36,558	-
100 Austria	28,171	28,171	28,180	26,701	29,824	28,833	+
101 Czech Republic	22,562	22,562	22,780	22,092	23,240	22,845	+
103 Hungary	22,720	22,720	22,716	22,646	22,772	22,699	+
105 Slovakia	16,561	16,561	16,846	17,101	16,574	16,847	-
109 France	25,125	25,125	25,234	25,238	24,949	25,072	-

Table 3. Future soybean yield projections (Continued)

Soybean	2009	2010	2020	2030	2040	2050	
110 Germany	10,000	10,000	10,081	10,074	10,047	10,018	+
113 Switzerland	27,075	27,075	27,415	26,940	28,103	28,157	+
114 United States	29,578	29,578	30,006	30,278	30,162	30,157	+
121 Romania	17,465	17,465	15,791	15,522	16,068	16,038	-
122 Ukraine	16,763	16,763	16,699	16,515	17,306	16,766	+
123 India	10,642	10,642	12,681	11,218	11,465	12,235	+
126 Sri Lanka	22,831	22,831	22,636	22,723	22,610	22,546	-
132 Iran	24,674	24,674	23,915	23,735	23,699	22,817	-
138 Kyrgyzstan	17,777	17,777	17,333	17,143	17,293	17,235	-
139 Nepal	9,138	9,138	9,125	9,137	9,131	9,134	-
140 Pakistan	6,000	6,000	6,000	5,815	5,810	5,890	-
141 Tajikistan	1,000	1,000	1,012	1,010	1,014	1,015	+
145 China	16,477	16,477	18,525	18,733	18,750	18,175	+
146 Japan	15,811	15,811	17,346	17,481	16,720	16,963	+
147 North Korea	11,666	11,666	11,803	11,878	11,808	11,849	+
148 Philippines	10,000	10,000	10,098	10,142	10,112	10,113	+
149 South Korea	19,857	19,857	20,629	20,824	20,483	20,378	+
150 Cambodia	14,574	14,574	14,823	14,858	14,936	14,767	+
151 Laos	15,373	15,373	15,718	15,818	15,835	15,623	+
153 Myanmar	12,121	12,121	11,675	11,593	11,555	11,741	-
154 Thailand	16,333	16,333	15,684	15,473	15,459	16,212	-
155 Vietnam	14,610	14,610	14,523	14,500	14,477	14,536	-
159 Kenya	8,400	8,400	8,394	8,394	8,398	8,396	-
162 Zambia	12,000	12,000	11,420	11,766	11,618	11,821	-
163 Zimbabwe	16,417	16,417	16,712	16,671	16,573	16,510	+
168 South Africa	21,703	21,703	17,890	17,159	17,318	16,735	-
174 Gabon	10,476	10,476	10,734	10,820	10,818	10,830	+
177 Madagascar	10,000	10,000	8,603	7,715	8,131	8,688	-
180 Indonesia	13,482	13,482	15,828	15,576	15,938	16,727	-
182 Australia	18,925	18,925	19,287	19,170	19,178	19,261	+

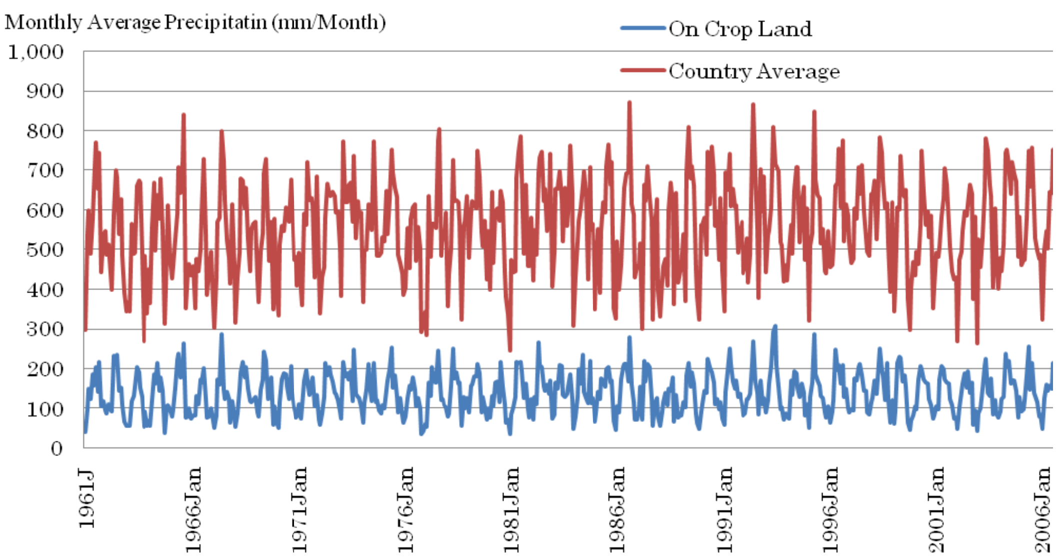

Figure 1. Comparison of country averaged precipitation and precipitation on crop area in USA

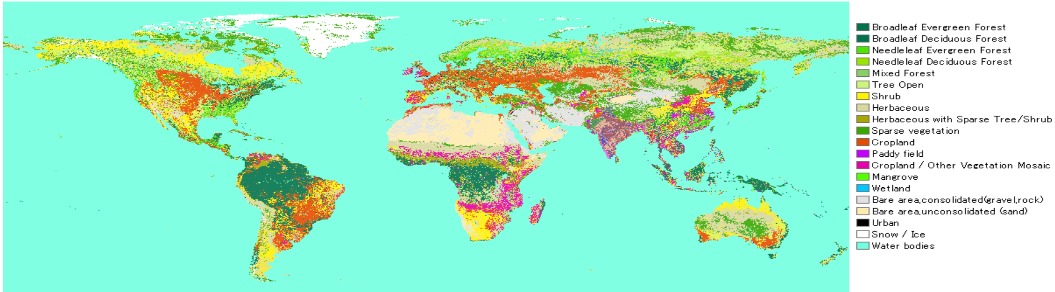

Figure 2. Global Land Cover (GLCNMO) Data

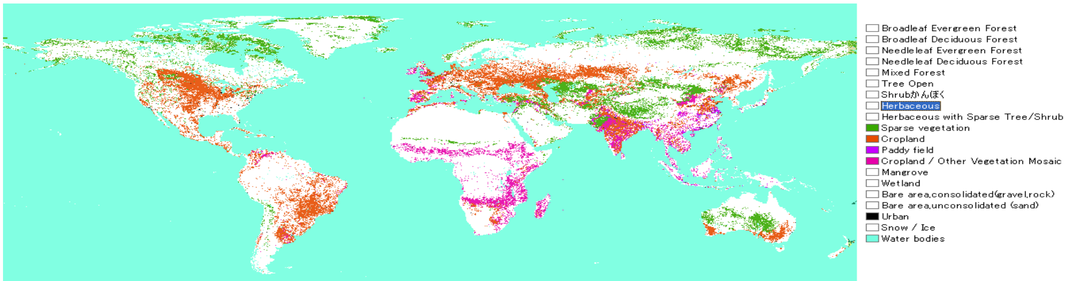

Figure 3. Extracted crop area from Global Land Cover (GLCNMO) Data

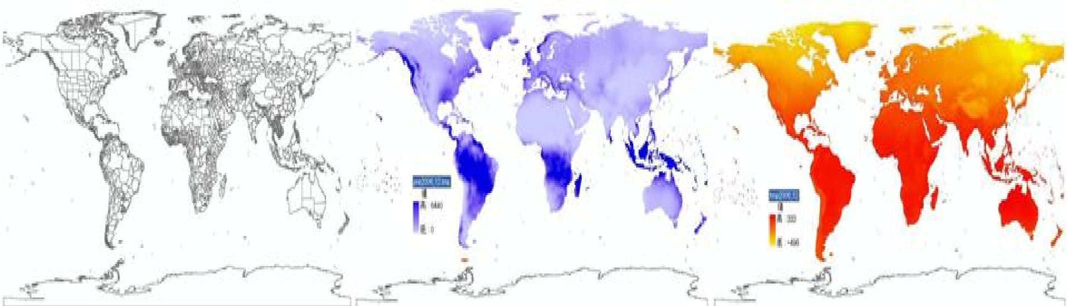

Figure 4. Boundary data (Right), Precipitation data (Middle), Temperature data (Left)

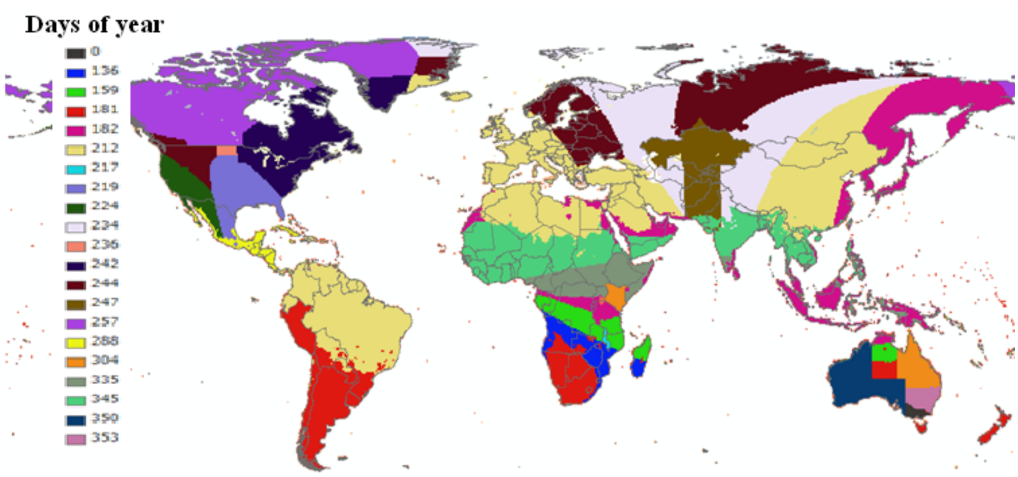

Figure 5. Rice cropping calendar (Harvesting days of year)

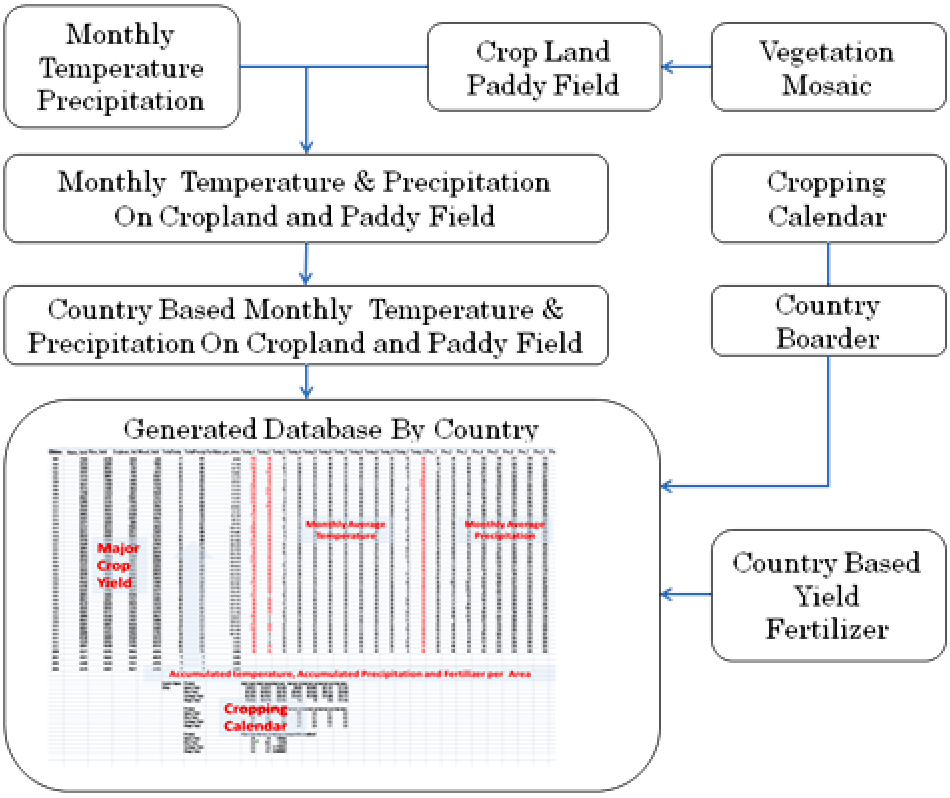

Figure 6. Overall conceptual framework to generate datasets for estimation

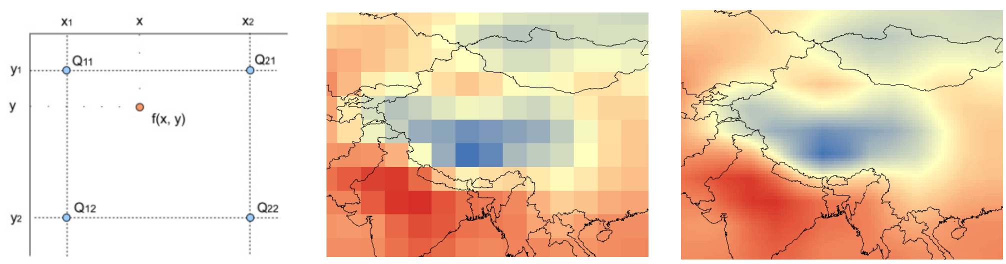

Figure 7. Bilinear Interpolation (Left), 3.75degree GCM (Middle), 0.5degree imposed GCM (Right)

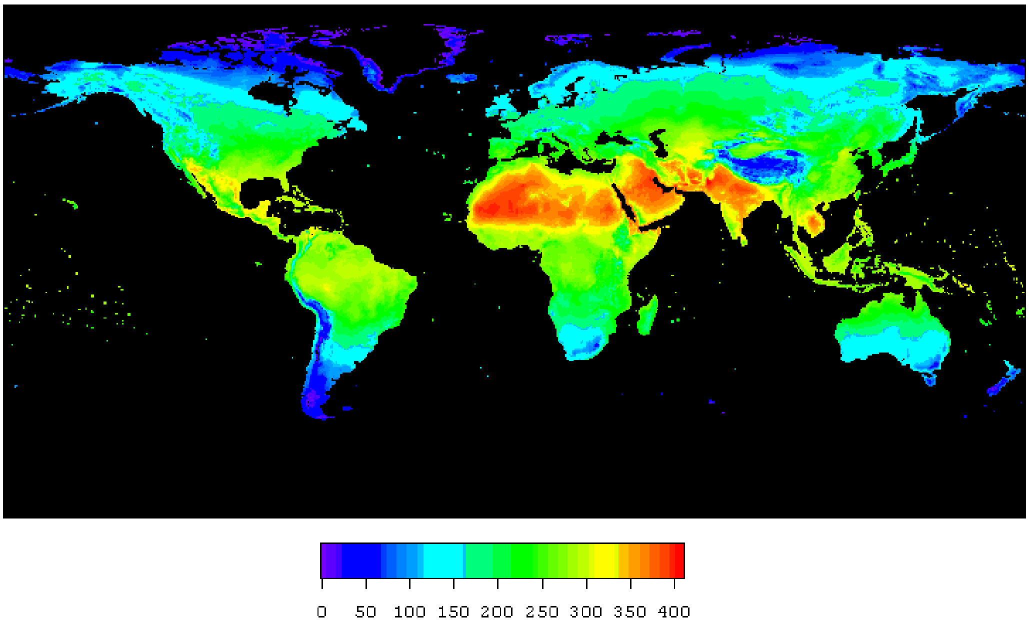

Figure 8. Average monthly dataset in June from 2041 to 2050

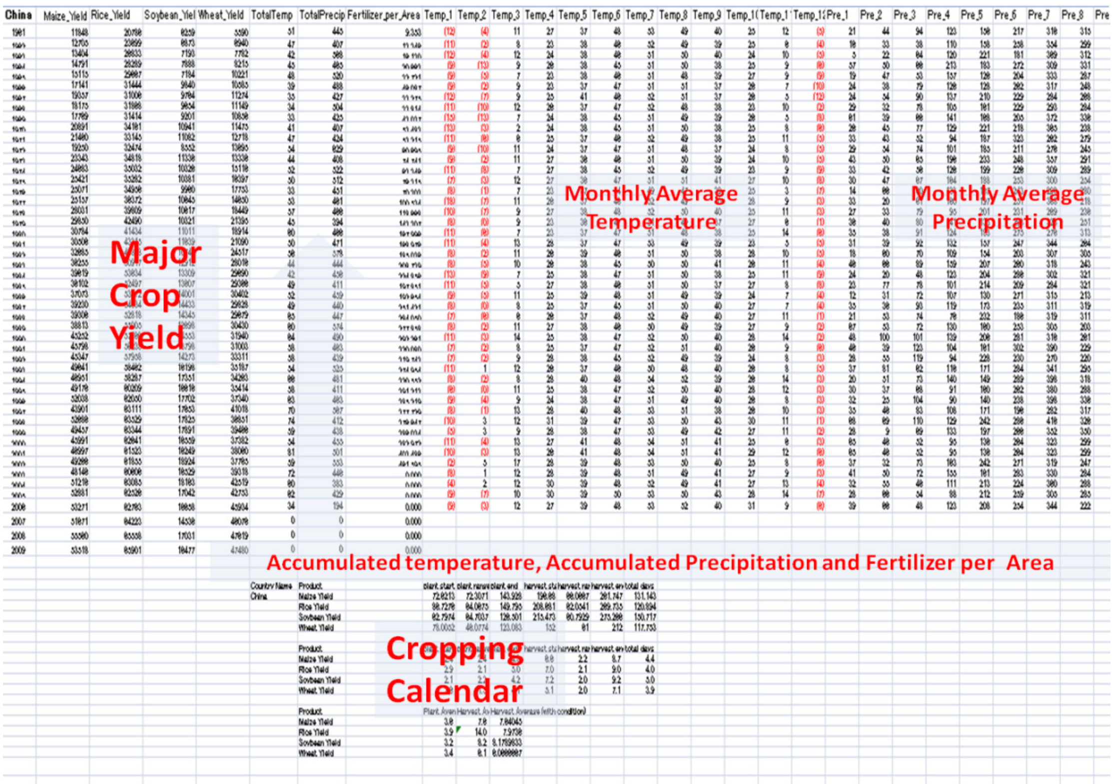

Figure 9. The structure of a generated data in China

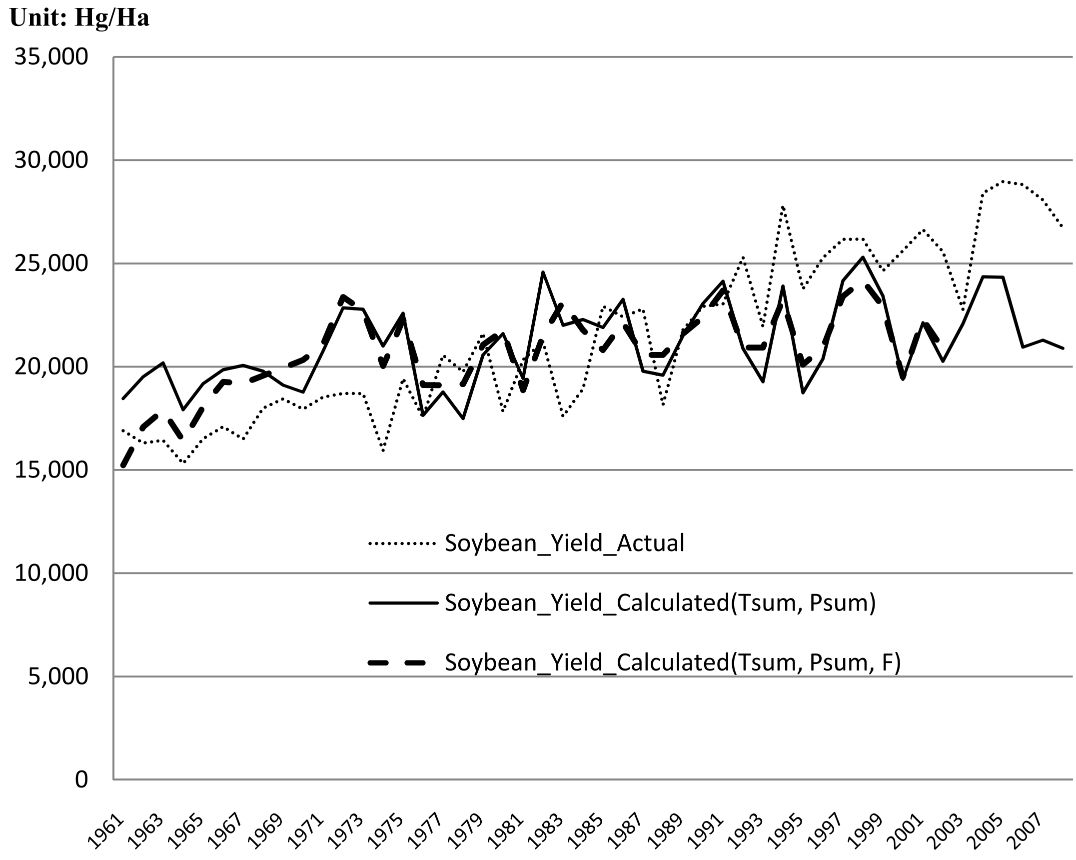

Figure 10. Actual, Case A and Case B of Soybean yield in USA