Influence of Climatic Variation on Soybean Yield in Japan and Asia

Sonia Hossain

1. Introduction

Soybean is one of the most important crops which supplies large part of vegetable protein and oil in the world. In fact, it is the 3rd most important crop in the world involving global annual trade of around 65 billion dollars. Literature review showed that recent global warming trend and associated climate change seem to impact on soybean production. However, the yield formation is rather complicate in comparison with cereal crops, obscuring quantitative effect of weather on the production. This study aimed to reveal the relationship between climatic variation and soybean yield. For the purpose, historical statistic data in Japan and major soybean producing countries of Asia were analyzed and results were verified through an experiment.

2. Influence of climatic variation on yield in Japan

Soybean yield varied widely from year to year and also from one region to another in Japan. These variations resulted from a variety of factors like differences in the cropping types, cultivars, agricultural policy, government subsidies among different regions and technological development over time. All these temporal and regional variations complicated the relation between yield and climate factors. To eliminate the effects of such non climatic factors on yield, classification of yield at prefecture level and year level is necessary. For this purpose, soybean yield data of 64 years (1948-2012) and 46 prefectures in Japan were collected from the Ministry of Agriculture, Forestry and Fisheries, Japan. These average yield data were first converted into standardized yield data by means of standardization to allow the comparison among prefectures and years and a pattern analysis was conducted by means of 2 way cluster analysis using statistical software CROPSTAT.

Pattern analysis classified yield variation into 9 distinct prefecture groups (PGs) and 9 year groups (YGs) based on the similarity of their prefecture to prefecture and year to year variation. These PGs consisted of varying number of prefectures ranging from 1 to 10. PG formation showed a spatial coherence with north to south variation as most north and north-eastern prefectures (15) were classified into 2 PGs: PG1 and PG2 while most south and south-western prefectures (20) were also classified into 2 PGs: PG 6 and PG8. Yield variation per planted area was largest in the middle part of the country followed by southern part compared to northern part as greater numbers of PGs were formed in middle part of the country followed by southern part and then in the northern part. YG formation indicated that yield has become highly variable in recent years compared to earlier years, as 4 YGs were formed within earlier 42 years (1948-1989) while 5 YGs were observed within only 22 years for the recent period (1990-2012). YGs were consisted of as large as 24 years (1952- 1979 excluding 1953, 1954, 1958) and as small as 1(2004) or 2 (1990, 1998) years. Nine YGs were divided into 2 periods each consisted of 4 YGs: period 1 (YG1, YG2, YG3, YG4; 1948-1989) and period 2 (YG5, YG6, YG7, YG9; 1990-2012) to study the relation between climate and yield. YG8 was excluded from this classification as it consisted of the year, 2004, when yield was remarkably affected by several numbers of typhoons.

Standardized yield of all the prefecture groups showed fluctuating pattern over the different year groups. Although standardized yield for most PGs is positive in most YGs some have more fluctuating pattern than others. PG 6 (consisted of southern prefectures: Hyogo, Tottori, Hiroshima, Yamaguchi, Toyama, Fukui, Ishikawa, Kyoto, Okayama, and Kagawa) showed highest degree of fluctuation compared to other PGs. On contrary, PG 7 (Osaka, Wakayama) had lowest fluctuation over the YGs. PG1 and PG8 had positive standardized yield in 6 out of 9 YGs, whereas other PGs had that in 5 or less YGs. This indicated that yield is consistently higher in PG1 (Hokkaido, Ibaraki, Tochigi, Gunma, Saitama, Chiva, Kanagawa, and Nagano) and PG8 (Nigata, Ehime, Shimane, Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima). This classification of prefectures and years provides a definite spatial temporal basis of yield variation to compare with the variations of climate.

To quantify the above defined effects of climatic variations on soybean yield, monthly climate data (average, maximum, minimum temperature, precipitation, sunshine duration) of relevant years and prefectures were collected from Japan meteorological agency. Monthly climatic anomaly of each YG in each PG was calculated from the average of the last 30 years standardized climate (1970-2000) and ANOVA was carried out for all PGs in period 1 and period 2 using statistical software CROPSTAT. In order to establish quantitative relationships among climate factors and yield stepwise multiple linear regression analysis was carried out using statistical software SPSS for all PGs in period 1 and period 2. Thus 2 equations for each PG for 2 periods were formed except for PG4, where only one equation was formed for period 1 and no equation was formed for period 2 as no climate factors had significant effect on yield.

ANOVA results indicated that some of the climate factors were significantly different among YGs in period 1 and period 2 for all PGs and this variation of climate factors among YGs seems to relate with the variation of standardized yield of YGs when compared. Multiple regression analysis for each PG in both periods supported and quantified these relations. In general, increase in temperature particularly for the month of July, August, September and October which had significant variations among YGs showed to improve yield in most of the locations among YGs in period 1 (PG1, PG2) and decrease yield among YGs in period 2. Excess rainfall in summer and autumn was quite common in most locations in period 1 and period 2 among YGs and showed to decrease yield. Increase in sunshine duration in period1 and period 2 affected the yield positively in most locations. Among all the climate factors sunshine duration and rainfall were the most consistent influential factors affecting yield. Two different regression equations for two periods indicated that negative factors have decreased from period 1 to period 2 in most PGs. These equations for two periods also indicated that precipitation in recent years affected soybean yield less than that in earlier years, while minimum temperature in recent years affected larger. These results suggest that soybean production in Japan became stable against precipitation while deterioration from increasing trend in minimum temperature becomes obvious.

3. Influence of climate factors on soybean yield in Asia

In order to analyze the effect of climatic variation on soybean production in Asia, historical weather data is required but most dataset lacks solar radiation data. This is because the equipment required for this is expensive, difficult to manage and vulnerable to malfunction and unavailable in most weather stations. Therefore one of the widely used empirical models (Hargreaves Samani model) to calculate solar radiation from the daily temperature range was validated using data from 10 locations of Japan due to its quality of data accuracy and availability for longer period.

The Hargreaves Samani model is written as follows-

$$R_s = K_{Rs} [R_a (1 + 2.7 \times 10^{-5} \times Alt) \{(Tmax-Tmin)^{0.5}\}]$$

Where, R_s = solar radiation at the earth surface, (MJ m^{-2} day^{-1}), R_a = extra terrestrial radiation (MJ m^{-2} day^{-1}), Tmax–tmin = difference between daily maximum and minimum temperature (^{o}C), K_{Rs} = model coefficient and Alt = altitude (m).

Using this model, at first K_{Rs} value (model coefficient) for the period of 1981-1985 and 2003- 2007 were calculated for 10 different locations in Japan which showed distinct decadal and seasonal pattern of variation due to global warming trend. Bias and RMSE were also calculated. The results showed that although decadal and seasonal variations must be taken into consideration, the application of model is acceptable for longer periods of time over broader regions.

To study the effect of climatic variation on soybean yield 11 major soybean producing countries of Asia: Turkey, Kazakhstan, China, South Korea, North Korea, Japan, India, Myanmar, Indonesia, Thailand, and Viet Nam were selected based on their contribution to the total production along with 2 leading soybean producing countries in the world: USA and Brazil. Planted area, production and yield statistics from 1982 to 2008 were collected from the crop production database of the Food and Agriculture Organization (FAO) of the United Nations and climate statistics (monthly average, maximum, minimum temperature, precipitation) were collected from 5-3 weather stations in major soybean producing areas of relevant countries. Solar radiation was calculated by the validated Hargreaves Samani model. Yield data were divided into 3 periods: 1982-90, 1991-99, and 2000-2008 for comparison and 2 set of regression analyses were performed using data from all countries for 3 periods with all climate factors and yield. The 1st set of regression consisted of annual climate and yield and the 2nd set consisted of summer climate and yield.

Soybean production and yield trend was mostly positive in all 3 periods in all countries though average yield was much lower in most countries compared to USA and Brazil. Yield improvement from one period to another was highest in Turkey and lowest in India and Myanmar. However, compared to USA and Brazil this yield improvement was also much lower in most countries in all 3 periods except for Turkey in 2000-2008. In general, yield was comparatively higher in the upper latitude temperate countries than tropical humid countries. Regression analysis revealed that yield had negative relation with annual temperature (average, maximum and minimum) and these negative relations were more evident with summer temperature in all 3 periods. Annual precipitation also showed a negative relation with yield above a certain level (>1500 mm) but not in all 3 periods. Negative relation between summer precipitations and yield is also more evident with summer precipitation than annual precipitation. Though no significant relation between annual solar radiation and yield was observed, a slight positive relation was found between summer solar radiation and yield. These indicated that the negative effect of summer temperature and precipitation during the last 27 years in Asia has become quite evident.

4. Experimental evaluation of high temperature effect on soybean yield formation

The effect of high temperature and water stress on yield formation was experimentally verified by investigating soybean grown in temperature gradient chamber at the experimental farm of Kyoto University at Kyoto City, Japan in 2011 and 2012. Two water treatments (control, drought) and 2 temperature treatments (ambient, high = ambient + 2°C) were imposed on 3 cultivars in 2011 (Enrei, Stressland, Tachinagaha) and 4 cultivars (Enrei, Stressland, Fukuitaka, UA 4805) in 2012. In vitro pollen germination was measured by collecting 10-15 flowers from 5 plants per treatment between 0800- 0900 h on the day of anthesis. Leaf photosynthesis and conductance were measured during flowering to pod set. At Maturity, 5 plants from each cultivar were used to calculate node number, pod number, seed size, seed number, seed yield and harvest index (HI). Pod set ratio was measured by counting the flower scar number and pod number at maturity.

Effect of temperature and water stress was statistically significant ($P<0.05$ to $P<0.01$) on pollen germination and all the yield components (flower number, pod number, podset ratio, seed number, single seed weight, yield). Cultivar difference was also significant in all yield components. Cultivar UA4805 and Fukuitaka were less affected by the stress condition than cultivar Tachinagaha and Enrei. Pollen germination, pod set ratio and seed yield reduction under high temperature and combined high temperature and water stress across all cultivar on average were 11% ─ 28%, 8% ─ 18% and 22% ─ 42% respectively. Seed number and Pod set ratio under stress condition was linearly correlated with pollen germination. Therefore, the results on the effect of high temperature support the above statistical analyses in terms that increased temperature negatively affects soybean yield.

5. General discussion and conclusion

This study identifies the distinct pattern of yield variation of soybean in Japan and contributes to quantify the effect of climatic variation on soybean yield. Although major weather disasters on soybean production are drought and excess rainfall, the results in this study suggests that soybean productivity is being potentially reduced in recent years due to increased temperature in Japan as well as in Asia. If present global warming trend continues, soybean yield might reduce remarkably. Therefore, the development of agronomic and breeding strategy against global warming should be an urgent issue.