Factors Causing the Soybean Yield Gaps between Japan and USA

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Abstract

The average soybean yield in Japan is stagnated around 1.7 t ha^{-1}, which is quite low level compared to that in USA (around 2.7 t ha^{-1}). The objective of this study was to reveal the factors causing this yield gap between Japan and USA. To examine the variety effect on the yield gap, we conducted yield test at Osaka (central Japan, 34^{o}51'N), Hokkaido (northern Japan, 43^{o}03'N), Feyetteville, AR (south-central USA, 36^{o}03'N), and Champaign, IL (mid-western USA, 40^{o}06'N), in 2009 using 4–6 Japanese and 5–10 USA varieties. Averaged yield of USA varieties was 8–59 % higher than that of Japanese varieties in each experimental site, which means the yield potential of USA varieties was higher than that of Japanese varieties. To examine the environmental effect on the yield gap, we estimated the potential yield (Y_p) at Hokkaido, Shiga (central Japan, 35^{o}16'N), Arkansas, AR (south-central USA, 34^{o}30'N), and Champaign, IL, by simple simulation model, where we assumed that Y_p was determined by solar radiation, air temperature and growth duration. Estimated Y_p in USA (7.34 t ha^{-1} in Arkansas and 7.12 t ha^{-1} in Champaign, averaged over recent 30–year) was higher than that in Japan (5.84 t ha^{-1} in Shiga and 4.69 t ha^{-1} in Hokkaido), and this difference was mainly brought from the difference in solar radiation intensity. Ratio of the actual yield to the potential yield (Y_a/Y_p) was highest in Champaign (50.7 %, averaged over recent 5–year), followed by Hokkaido (44.6 %), Arkansas (38.9 %), and the lowest in Shiga (24.6 %). In addition, there were increasing tendencies in Y_a/Y_p in USA (0.23–0.50 % year^{-1}), while no such a tendency in Japan. The increasing tendencies in Y_a/Y_p in USA would be brought from the improvement of crop management in addition to breeding new varieties.

*Keywords: soybean (*Glycine max *(L.) Merrill), Yield*

Introduction

Improvement on soybean (*Glycine max* (L.) Merrill) production in Japan is strongly needed, because soybean self-sufficiency ratio in Japan is quite low (around 5%; MAFF, 2011a). Soybean yield in Japan has been stagnated around 1.7 t ha^{-1} (MAFF, 2011b) in recent years, while that in USA, the largest producer of soybean in the world, has increased steadily in the last few decades and reached around 2.7 t ha^{-1} (USDA-NASS, 2009). It is not clear, however, how varieties, environment and crop management have affected on this growing gap soybean yield between Japan and USA. The objective of this study is to clarify the factors causing soybean yield gaps between Japan and USA.

In the present study, we grew Japanese and USA commercial soybean varieties in northern and central Japan and mid-western and south-central USA, where are the major producers of soybean in Japan and USA. The objectives of this study were (1) to examine the yield potential (Y_p) of Japanese and USA varieties and study the varietal effect on the growing yield gap, (2) to estimate the changes of Y_p in northern and central part of Japan and mid-western and south-central USA using a simple simulation model, with the assumtion that Y_p was determined by solar radiation, air temperature and growth duration, (3) to compare the Y_p in Japan and USA, and (4) to study the environmental and crop management effects on the growing yield gap between Japan and USA bycomparing the changes of Y_a/Y_p.

Materials and Methods

Eight Japanese and 14 USA commercial varieties (Suzukari, Enrei, Suzuyutaka, Tachinagaha, Sachiyutaka, Tamahomare, Toyomusume and Yuzuru for Japanese varieties and Athow, Omaha, Manokin, LD003309, 5002T, UA–4805, Osage, 5601T, Ozark, Hutcheson, Jack, Williams82, X34 and X88 for USA varieties) were used in the present study. 4–6 Japanese and 5–10 USA varieties were grown in Osaka (central Japan, $34^{o}51'$N), Hokkaido (northern Japan, $43^{o}03'$N), Feyetteville, AR (south-central USA, $36^{o}03'$N), and Champaign, IL (mid-western USA, $40^{o}06'$N) during the summer season in 2009. Crop managements, such as sowing date, planting density, fertilizer application rate, and so on, were based on the common practices in each experimental site. Experiments were consisted of 3-4 replications. Soybean yield was determined at maturity by harvesting more than $1m^2$ area from each replication.

Based on the meteorological statistics and crop progress reports, changes of Y_p were estimated by the following simple simulation model.

$$Y_p = HI \cdot \sum_{n=1}^{d} \left[RUE \cdot \{1 - \exp(-k \cdot LAI) \cdot Rad\} \right]$$

where, HI is harvest index, RUE is radiation use efficiency, k is light extinction coefficient, LAI is leaf area index, and Rad is solar radiation. LAI was estimated by the logistic function of cumulative effective temperature with the base temperature being 8 ^{o}C. RUE in Japan was setup at 1.1 g MJ^{-1} for pre–R1+25–day period, and 0.77 g MJ^{-1} for post–R1+25–day period, based on the observed data under ideal conditions in Japan. RUE in USA was setup 10% lower than that in Japan, in consideration that RUE decreased under intense radiation environment. HI and k were assumed to be 0.5 and 0.6, respectively.

Potential yield (Y_p) was estimated for Shiga (central Japan, $35^{o}16'$N), Hokkaido, Arkansas, AR (south-central USA, $34^{o}30$), and Champaign, IL. Data from 1980 to 2009 for weather, crop calendar and statistics of soybean yield in each site were collected. Actual yield (Y_a) and Y_a/Y_p were analyzed for the field with and without irrigation system separately in Arkansas, because irrigation system has been rapidly spreading in south-central USA,

Results and Discussion

The seed yields observed in the variety tests are listed in Table 1. There was large variation in yield, which ranged from 2.12 to 5.91 t ha^{-1} depending on the varieties and sites (Table 1). Averaged yield of USA varieties (4.06–5.20 t ha^{-1}) was 8–59 % higher than that of Japanese varieties (2.63–3.80 t ha^{-1}) in each site, which means the yield potential of USA varieties was higher than that of Japanese varieties.

As for the meteorological statistics in the four assessed locations, there was not so big difference in effective growth period (98–105 days, from emergence to leaf yellowing) among the sites, while radiation intensity in USA (20.9–21.4 MJ m^{-2} d^{-1}) was more than 30 % larger than that in Japan (15.5–16.1 MJ m^{-2} d^{-1}) (Table 2). As a result, estimated Y_p in USA (7–8 t ha^{-1}) changed higher than that in Japan (5–6 t ha^{-1}), which showed the soybean potential yield in USA was higher than that in Japan, mainly because of solar radiation intensity (Figure 1). The values of Y_p on recent 30-year average in Shiga, Hokkaido, Arkansas, and Champaign were 5.84, 4.69, 7.34, and 7.12 t ha^{-1}, respectively.

Actual yield in Japan (1.56 and 2.17 t ha^{-1} on recent 30-year average, in Shiga and Hokkaido, respectively) was lower than that in USA (2.56, 1.72 and 3.04 t ha^{-1} on recent 30-year average, in Arkansas with irrigation system, Arkansas without irrigation system, and Champaign, respectively) (Figure 1). There were increasing tendencies in actual yield in all the sites, but the increasing rates were larger in USA (37.3, 20.2 and 35.1 kg ha^{-1} year^{-1}, in Arkansas with irrigation system, Arkansas without irrigation system, and Champaign, respectively) than those in Japan (0.9 and 12.5 kg ha^{-1} year^{-1}, in Shiga and Hokkaido, respectively). In addition, the increasing rates in Y_p was very small (14.5 and 35.1 kg ha^{-1} year^{-1}, in USA, which means that the changes in Y_p could not explain the recent soybean yield increase in USA.

Table 1. Yield (t ha^{-1}) of Japanese and USA soybean varieties grown under Osaka, Feyetteville, Champaign, and Hokkaido in 2009

	Osaka 34°51'N	**Hokkaido** 43°03'N	**Feyetteville** 36°03'N	**Champaign** 40°06'N
Japanese varieties				
Suzukari	3.64	4.51		2.85
Enrei	3.93		3.23	2.86
Suzuyutaka	4.13	3.09		2.68
Tachinagaha	3.10		3.44	
Sachiyutaka	4.16		3.60	
Tamahomare	3.44		3.48	
Toyomusume		3.28		
Yuzuru		4.32		2.12
Average	**3.73**	**3.80**	**3.44**	**2.63**
USA varieties				
Athow	5.07	4.87		3.88
Omaha	5.91	4.35		4.25
Manokin	5.23		4.70	
LD003309	5.06	3.13		4.66
5002T	4.69		5.73	
UA4805	5.15		4.44	
Osage	5.19		4.72	
5601T	5.50		5.32	
Ozark	5.19		4.23	
Hutcheson	5.03		4.85	
Jack		4.04		4.11
Williams82		4.20		3.95
X34 (LJ)		3.61		
X88 (LJ)		4.24		
Average	**5.20**	**4.06**	**4.86**	**4.17**

Table 2. Season of soybean cropping and its climate summary

	Latitude	Mean peak date*		Effective growth period** (days)	Total rainfall (mm)	Daily temperature		Daily solar radiation (MJ m^{-2} d^{-1})
		Planting	Harvesting			Max (°C)	Min (°C)	
Shiga, Jpn	35°16'	23 Jun	4 Nov	103	581	28.4	21.4	15.5
Hokkaido, Jpn	43°03'	23 May	9 Oct	102	333	23.9	16.7	16.1
Arkansas, USA	34°30'	24 May	13 Oct	105	261	32.4	21.0	20.9
Champaign, USA	40°06'	22 May	4 Oct	98	341	28.7	17.1	21.4

*, based on the crop progress report of Shiga and Hokkaido (1980-1997), East Illinois (1980-2005), and East Central Arkansas (1996-2008).

**, Emergence to leaf yellowing. The climate data were calculated for the effective growth period based on the meteorological statistics from 1980 to 2009 for the districts on Japan and USA respectively.

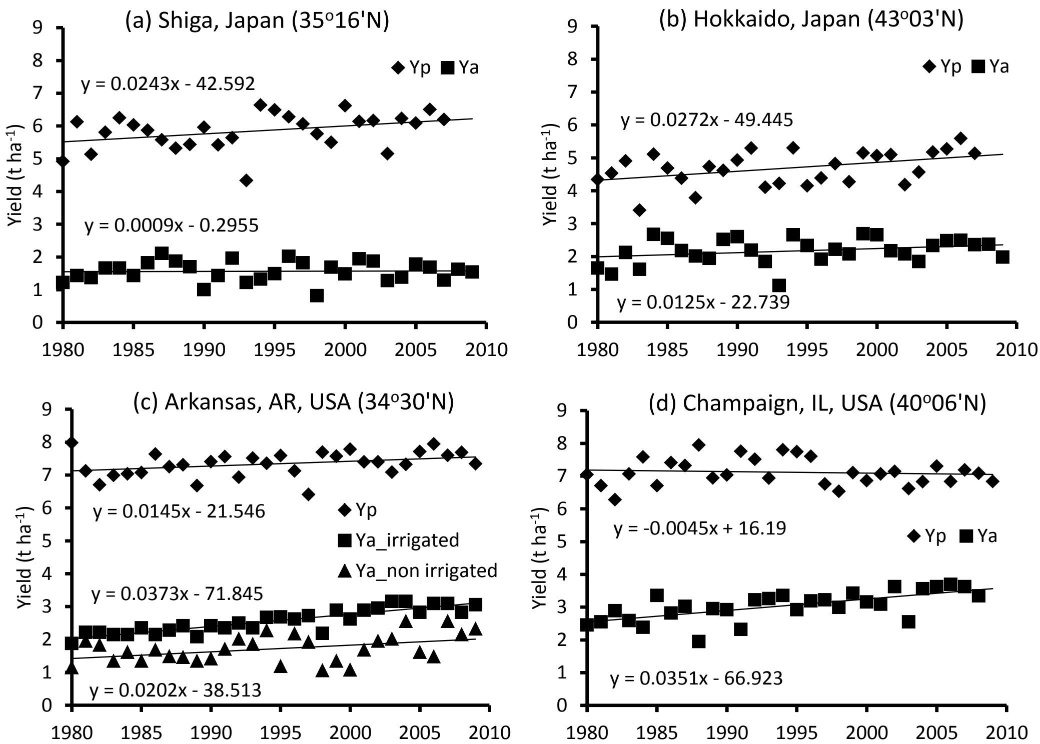

Figure 1. Changes of estimated potential yield (Y_p) and actual yield (Y_a) in (a) Shiga, (b) Hokkaido, (c) Arkansas, and (d) Champaign.

The Y_a/Y_p was the largest in Champaign (50.7 %, the recent 5 year average), followed by Hokkaido (44.6 %), Arkansas with irrigation system (38.9 %), Arkansas without irrigation system (26.5 %), and the lowest in Shiga (24.6 %) (Figure 2). As is the case in actual yield, there were increasing tendencies in Y_a/Y_p in USA (0.23–0.50 % year^{-1}), while no such tendency in Japan. We assumed that the increase in Y_a/Y_p in USA is brought from the improvement in crop management, such as increased adoption of irrigation system, introduction of early cultivation and raised bed planting, improvement in weed management, in addition to the developing and utilizing new high yielding varieties.

In the present study, we tried to reveal the factors causing the soybean yield gaps between Japan and USA focusing on environmental, varietal, and technological factors. Our results show that the greater amount of solar radiation is the major factor of higher yield in the USA and that the technological developments have caused the increase in yield gap between Japan and USA. There is still much room for improving soybean yield in Japan.

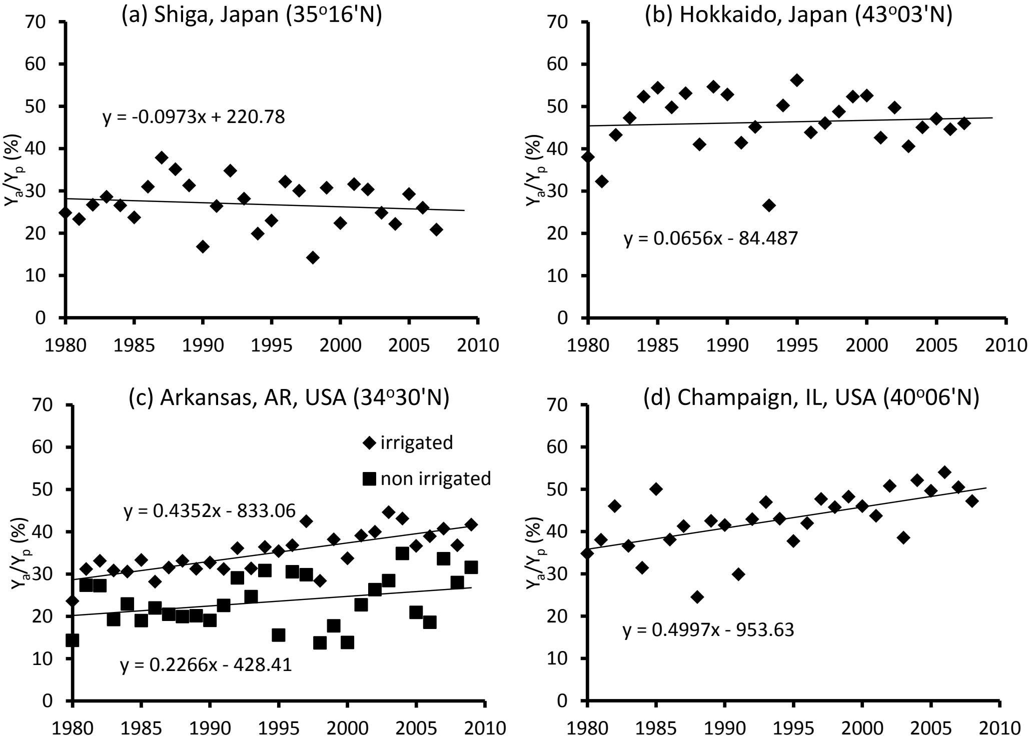

Figure 2. Changes of ratio of the actual yield to the estimated potential yield (Y_a/Y_p) in (a) Shiga, (b) Hokkaido, (c) Arkansas, and (d) Champaign.

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