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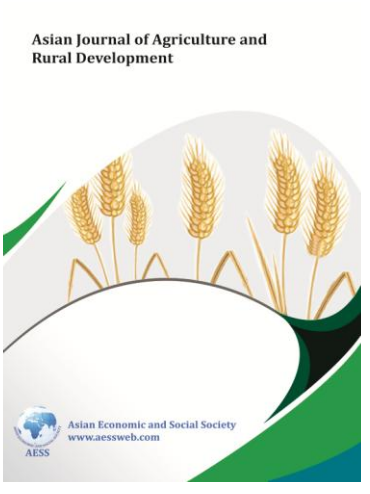

Trends and Variability of Rice, Maize, and Wheat Yields in South Asian Countries: A Challenge for Food Security

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Trends and Variability of Rice, Maize, and Wheat Yields in South Asian Countries: A Challenge for Food Security

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Abstract

During the last six decades, the yield and production of rice, maize, and wheat grew remarkably in South Asian region. As these cereals are staple foods, the growth and fluctuation of yields greatly impacts on food security. This study aims to examine the growth patterns and variability of rice, wheat, and maize yields in South Asian countries namely Bangladesh, India, Nepal, Pakistan, and Sri Lanka. Utilizing the yield data during 1961-2010, we applied the linear and quadratic regressions for yield trends and variability analyses. Quadratic model was fitted well in all data sets except wheat yield in Pakistan. A clear indication of slowing growth rates was observed for wheat yield in Bangladesh and India, as well as a significant increase in maize yield variability was realized in Bangladesh, India, Pakistan, and Sri Lank. The factors influencing for slowing yield growth rates are considered as comparative disadvantage of wheat to Boro rice in case of Bangladesh, whereas depletion of soil nutrient contents in the rice-wheat production areas and negative impact of climate change in India. The slowing yield growths exerted a challenge for food security in Bangladesh and India. Thus, policy implementations are urgent to improve the wheat yield growth and maize yield stabilization in the concerning countries.

Keywords: yield trend, growth pattern, yield variability, South Asia

Introduction

Over the years, production and productivity of some crops increased remarkably at global, regional, and national levels. Improved technology, agricultural practices, high-yielding varieties, plant protection measures, chemical fertilizers, and mechanization have been the drivers of increased production per unit area of farm land (Hobbs and Morris, 1996). By this, a desired quantity of food-grain is produced, thereby, meeting the demand for growing populations in one hand, whereas, a more instable production is realized on the other hand (Larson et al, 2004). Apparently, demand for food is continuously rising as the global population is projected to reach 9.1 billion in 2050 (United Nations Population Division, 2000). Thus, an understanding of yield growth vis- a'- vis production growth and inter annual fluctuation is necessary for short term and long term planning of food requirement at national and global level. Accordingly, recent literatures have paid attention to study the pattern of crop yield growths and its fluctuations.

Recent literatures presented evidences of slow growth of yields of different crops in different countries. Hafner (2003) reveals declining yield trends in the rice-wheat system. Supporting this, Tirol-Padre and Ladha (2006) state negative trend of rice yield with a varying magnitudes in a field experiment based study. Likewise, two comprehensive studies by Hafner (2003) and Calderini and Slafer (1998) found evidence of slow yield growth in some countries. To justify these slow growth evidences, ecologists assume the yield trend will go negative due to biophysical constrain as it will meet the saturation level.

South Asia is a good example that achieved tremendous progress in cereal production through Green revolution in the last decades (Alauddin and Quiggin, 2008). However, these past progresses need to be sustained in order to continue to feed its rapidly growing population. Some studies indicated rapid yield growth of the past has slowed down in some crops, particularly wheat (Hobbs and Morris, 1996). Accordingly, Hobbs and Morris (1996) show a projection of negative balance of rice and wheat for food requirements in India, Bangladesh, Pakistan, and Nepal in 2020. Moreover, in the case of yield instability, there are conflicting results as to whether the green revolution increased yield instability in this region. Alauddin and Tisdel (1988) reported increased stability for yield in Bangladesh; however, Larson et al. (2004) presented contradictory evidence of increasing yield instability in the case of India. Therefore, there is the need to rightly understand the issue of yield instability in these regions.

Considering the issue of slowing growth and instability, this study takes an example of rice, maize, and wheat yields in Bangladesh, India, Nepal, Pakistan, and Sri Lanka in South Asian region. Rice, wheat, and maize are sources of staple food in these regions and were taken as priority commodities during the Green Revolution period. Moreover, the yields and productions change and fluctuation of these crops greatly impacts for food security. Thus, research and development programs are in the top priority for these crops as they are considered the supplier of staple foods. The objective of the study is to examine the growth patterns and variability of rice, wheat, and maize yields in South Asian Countries namely Bangladesh, India, Nepal, Pakistan, and Sri Lanka.

The next section of this paper discusses the data and analysis models. In the third section, we discuss the results following the discussion in the fourth section. The final section is on the concluding results of the study along with some policy implications.

Materials and Methods

Models for Yield Trend Analysis

We followed the models of Finger (2010) and Hafner (2003) for yield growth trend analysis. For this, annual yield data were fitted in two ordinary least square models i.e. linear and quadratic. The linear model is

$$\hat{y}_{jk} = \beta_0 + \beta_1 t \qquad (1)$$

where $\hat{y}_{jk}$ denotes the predicted yields of crop k in country j and is linearly conditional on time t. In the linear model, β_0 is an intercept and β_1 is a coefficient of annual yield change. Annual yield change is assumed to be constant over the time.

Additionally, the yield series might get the saturation point. If the saturation point is evident, the series might fit a quadratic model. The quadratic model is

$$\hat{y}_{jk} = \beta_2 + \beta_3 t + \beta_4 t^2 \qquad (2)$$

where t^2 is squared time index. β_2, β_3, and β_4 are intercept, linear trend, and quadratic term, respectively. Following the quadratic model, yield series assumed to be nonlinear. The quadratic model is considered better fitting over linear model if and only if β_4 is significant at .05 level with a better fitted value. Even though, different forms of regression are applied in literature, for the sake of conciseness, we applied linear and quadratic yield growth modelling, in this study.

As Hafner (2003) suggested, average annual yield growth was categorized in five categories i.e. substantial growth, moderate growth, slowing growth, decline growth, and no trend. For this, our alternative hypotheses were adopted as $\beta_1 > 33.1$ kg per hectare for substantial growth, $\beta_1 > 0$ for moderate growth, $\beta_3 > 0$ and $\beta_4 < 0$ for slowing growth, and $\beta_1 < 0$ for decline. One tailed t- test was applied to test the hypotheses.

The outliers in the time series data may greatly influence the results. One outlier might be sufficient to depart the results apparently from the actual one. Thus, we employed re-weighed least square (RLS) regression to minimize the effect of outliers. Re-weighed least square (RLS) is considered a robust technique compared to the OLS. Two steps are followed in RSL technique. In the first step, the outliers are detected in the data series by using Least Trimmed Squares (LTS). The basic idea of LTS is to identify the outliers with the leverage effect which notably deviate the results that may come from the majority of data. In the next step, the recognized outliers from the first step are trimmed to estimate the regression coefficients. The LTS fitting criteria explained by Hafner (2003) is

$$\underset{\hat{\beta}}{\text{Min}} \sum_{i}^{h} (r^2)_t \qquad (3)$$

$(r^2)_t$ are the ascending order squared residuals estimated from robust model, and h is a trimming constant[1]. The LTS is only applied for the outlier identification because it is considered a low efficiency estimator as compared to RLS. Therefore, RLS regression is applied in the second step as a weighted least square (WLS) regression, which gives the zero weight to the outlier observations. Moreover, RLS estimator is robust and efficient in both conditions either presence or absence of the outliers.

Models for Yield Variability

The residuals are applied for the yield variability estimation because the results from the non de-trended yield will be biased as the yields tend to grow upward due to technological evolution over the period. We followed the regression model to estimate the yield variability as explained by Finger (2010) and Alauddin and Tisdel (1988). According to Finger (2010) yield variability is the absolute residual of the yield growth trend estimation i.e. absolute difference between observed and predicted yield $|r_{jk}|=|\ y_{jk}-\hat{y}_{jk}|$. The linear regression model is fitted to the absolute residuals that are estimated based on the linear RLS regression. The linear regression model is

$$|r_{jk}| = \alpha_0 + \alpha_1 t \qquad (4)$$

where α_0 and α_1 are the intercepts and the coefficients of annual change. Over the time, a significantly positive α_1 indicates increasing absolute yield variability and vice versa.

Additionally, we also estimated relative yield variability in this study. Relative yield variability is defined as the ratio of the absolute regression residuals to the predicted yield (Finger 2010). Basically, relative yield variability is appropriate for the yield series that show upward trend of growth. The relative yield variability is closely related to the coefficient of variation. The relative residuals are fitted to the linear model is

$$|r_{jk}|/\hat{y}_{jk} = \alpha_2 + \alpha_3 t \qquad (5)$$

Where α_2 and α_3 are the intercepts and the coefficients of annual change. By the definition, significantly positive α_3 indicates increasing relative yield variability, and vice versa.

Data

The study utilized 50 years time series yield data of rice, wheat, and maize in Bangladesh, India, Nepal, Pakistan, and Sri Lanka from 1961 to 2010 . However, in Sri Lanka, yield data for wheat were not recorded. The yield data are taken from the website of the United Nation's Food and Agricultural Organization (FAO) and converted to kilograms per hectare. In literature, studies have been using FAO data considering it as a reliable source. Therefore, we utilized FAO data for our study. The selected cereals are sources of staple food grains in the studied countries. As a production value, rice is ranked as the first crop in all study countries. Similarly, wheat is the second major crop in Bangladesh, India, and Pakistan. Maize is the second major crop in Nepal and Sri Lanka (FAO, 2012). Moreover, productions of these crops in those studied countries are ranked in a good position in the world production ranking. Therefore, rice, maize, and wheat are the major crops in South Asia from an economic point of view. As long term farm level yield data are not available, we applied national level aggregate data for the study. However, we are

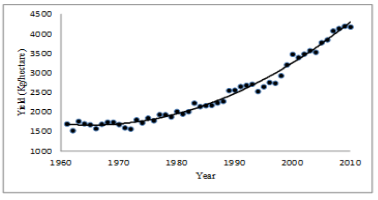
[1] H = [(3n+p+1)/4], where n is number of observations,

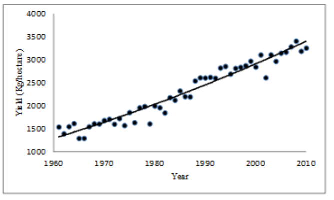
aware that there is a chance to under-estimate yield variability by using aggregate data.

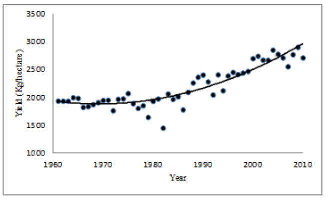
Results

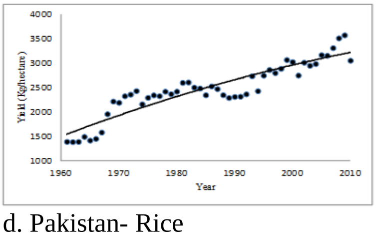
Yield Trend

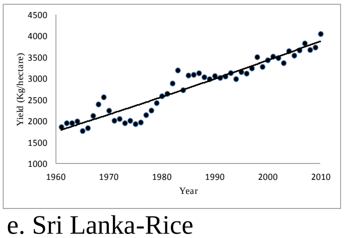
The changes of median yields of rice, maize, and wheat in the study countries were varied across crop in country from 1961-1965 to 2006-2010. Wheat yields in Nepal increased about 9 percent from 1961-1965 to 2006-2010, which showed the lowest among data sets in this region. In contrast, maize yield in Bangladesh increased tremendously about 675 percent during the same period. Out of 14 data sets, one third sets were increased by more than 200 percent; one third with more than 100 percent, and the remaining 4 sets increased less than 100 percent during the study period. The scatter plot and yield trends of rice, maize, and wheat are shown in Figure 1.

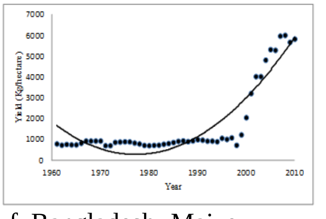

a. Bangladesh- Rice

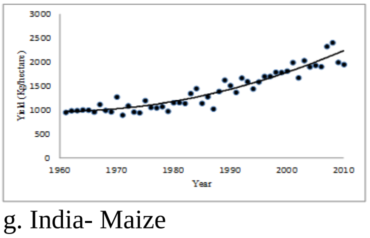

b. India- Rice

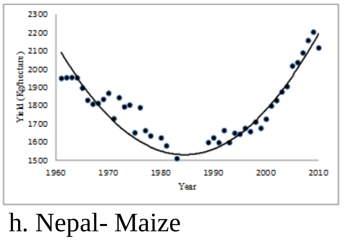

c. Nepal- Rice

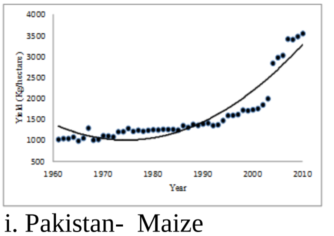

d. Pakistan- Rice

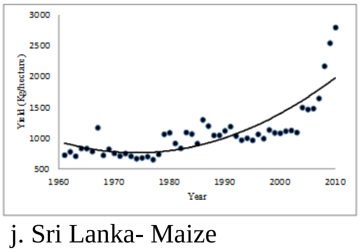

e. Sri Lanka-Rice

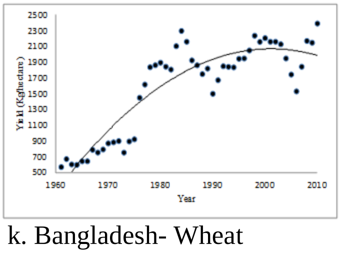

f. Bangladesh- Maize

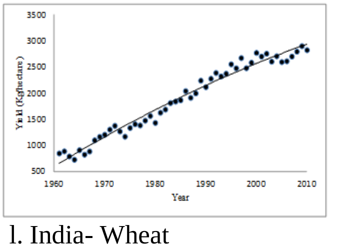

g. India- Maize

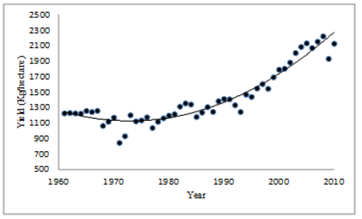

h. Nepal- Maize


i. Pakistan- Maize

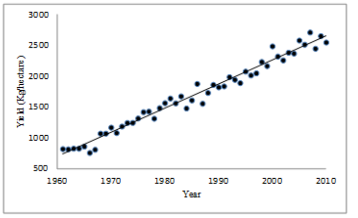

j. Sri Lanka- Maize


k. Bangladesh- Wheat


l. India- Wheat



m. Nepal- Wheat



n. Pakistan-Wheat

Figure 1: Yields of rice, maize, and wheat in Bangladesh, India, Nepal, Pakistan, and Sri Lanka (1961-2010). Note: Note: rice, and maize in all countries and wheat in Bangladesh, India, and Nepal are fitted quadratic model (equation (2)) and wheat in Pakistan is fitted linear model (equation (1)). Source: FAO (2012).

Results of linear and quadratic regression models are presented in panel A and B of Table 1, 3, and 4, respectively. Linear regression results in Table 1 show a significantly positive growth in rice yield in all countries with about 42 kg per hectare annual yield increment in Bangladesh, India, and Sri Lanka, respectively. In addition, quadratic regression results show a significantly positive polynomial coefficient and it outperforms the linear regression to account the yield growth in all countries. Therefore, we selected the quadratic model for rice.

Table 1: Robust Regression Estimates for Linear and Quadratic Model of Rice

Panel A: Linear Model				
Countries	β_0	β_1		R^2
Bangladesh	1291.383(60.791)***	42.348(2.447)***		.89
India	1209.252(44.425)***	42.607(1.516)***		.97
Nepal	1668.215(49.384)***	21.065(1.678)***		.78
Pakistan	1592.222(65.097)***	34.278(2.222)***		.77
Sri Lanka	1721.566(58.449)***	42.634(1.995)***		.95
Panel B: Quadratic Model				
Countries	β_2	β_3	β_4	R^2
Bangladesh	1702.159(45.374)***	-13.803(4.104)***	1.315(.078)***	.98
India	1282.164(58.262)***	35.271(5.301)***	.152(.101)***	.97
Nepal	1924.278(58.080)***	-8.829(5.298)***	.587(.101)***	.90
Pakistan	2332.420(137.140)***	-13.465(10.504)	.694(.177)***	.82
Sri Lanka	1750.272(90.720)***	39.321(8.206)***	.065(.156)***	.95

Note: values in parentheses are standard errors and '***' indicates significant at the 0.01 level.

For maize, results from linear and quadratic model are presented in Table 2. Annual growth of the yield from linear model is ranged about 2 to 25 kg per hectare in the studied countries. In all countries, the results of the polynomial coefficient of the quadratic model are positively significant at least at .05 level. Therefore, we selected quadratic model for all countries.

Table 2: Robust Regression Estimates for Linear and Quadratic Model of Maize

Panel A: Linear Model				
Countries	β_0	β_1		R^2
Bangladesh	758.641(33.201)***	5.694(1.447)***		.24
India	765.225(44.208)***	24.979(1.535)***		.86
Nepal	1689.838(61.123)***	2.097(2.086)		.21
Pakistan	946.015(26.721)***	17.302(1.083)***		.87
Sri Lanka	678.728(44.020)***	12.601(1.631)***		.67

Panel B: Quadratic Model				
Countries	β_2	β_3	β_4	R^2
Bangladesh	857.603(41.966)***	-9.956(4.921)**	.424(.122)***	.37
India	1007.588(55.917)***	-5.334(5.264)	.645(.104)***	.93
Nepal	2138.781(36.909)	-48.867(3.358)***	.996(.064)***	.88
Pakistan	1065.705(30.232)***	-1.274(3.120)	.456(.068)***	.94
Sri Lanka	780.034(67.737)***	-.773(6.510)	.300(.132)**	.66

Note: values in parentheses are standard errors and '***', and '**' indicate significant at the 0.01 and 0.05 level, respectively.

In Sri Lanka, yield data for wheat were not recorded; therefore, we analyzed data from four countries only. Results from linear and quadratic models are shown in Table 3. The linear model reveals yield increment for wheat at about 47, 39, 34 and 22 kg per hectare in India, Pakistan, Bangladesh, and Nepal, respectively. In addition, yields in Bangladesh, India, and Nepal showed significant results for second order polynomials and better goodness of fit in three countries compared to the linear model. However, the coefficient for second order polynomials is insignificant for wheat in Pakistan. Therefore, we select the quadratic model in Bangladesh, India, and Nepal, whereas the linear model for wheat in Pakistan. For wheat, quadratic model shows interesting results with negative and significant coefficient for second order polynomials in Bangladesh and India.

Table 3: Robust Regression Estimates of Linear and Quadratic Model for Wheat

Panel A: Linear Model				
Countries	β_0	β_1		R^2
Bangladesh	726.484(92.011)***	33.620(3.140)***		.80
India	700.994(35.818)***	46.640(1.223)***		.98
Nepal	870.974(55.255)***	21.688(1.867)***		.51
Pakistan	700.458(26.927)***	39.001(.919)***		.97
Panel B: Quadratic Model				
Countries	β_2	β_3	β_4	R^2
Bangladesh	253.108(110.528)**	88.240(9.998)***	-1.071(.190)***	.85
India	594.473(51.809)***	58.931(4.686)***	-.241(.089)***	.98
Nepal	1308.053(33.207)***	-26.065(3.117)***	.943(.062)***	.92
Pakistan	707.698(41.848)***	38.175(3.785)***	.016(.072)	.97

Note: values in parentheses are standard errors and '***' and '**' indicate significant at the 0.01, 0.05 level, respectively.

The t statistics results showed the growth of rice yields in Bangladesh, India, Pakistan, and Sri Lanka were substantial because coefficients of β_1 in those countries are significantly greater than 33.1 kg per hectare at .05 level. However, rice yield growth in Nepal was moderate because coefficient of β_1 is significantly positive. In case of Maize, annual yield growths were only moderate in Bangladesh, India, Pakistan, and Sri Lanka because coefficients of β_1 are significantly positive (greater than 0 kg per hectare) at .01 level. In contrast, yield growths of maize in Nepal showed no trends because coefficient of β_1 is not significantly positive (no difference with 0) at 0.05 level. Similarly, yields growths of wheat in Bangladesh and India showed a slowing growth because coefficients of β_3 and β_4 are significantly positive and significantly negative at 0.01 level respectively. However, yield growths in Nepal and Pakistan were moderate and substantial because β_1 in those countries are significantly positive and greater than 33.1 kg per hectare at 0.01 level respectively[2].

[2] The estimated t values are not presented here; it will be available upon request. The d.f considered for significant tests are 47 for linear model's coefficients and 46 for quadratic model's coefficients because d.f equal n-k-1 in the OLS regression analysis

Yield Variability

The selected linear or quadratic models were used to estimate the absolute and relative residuals in all data sets. Applying equation (4), we estimated absolute yield variability. Absolute yield variability indicates that the higher the absolute residual, the higher the yield variability, and vice versa. Therefore, a positive and significant time trend indicates the increasing yield variability for the crop. The results of rice, maize, and wheat yield variability are presented in Table 4, panel A, B, and C, respectively. In case of rice, none of the countries show a positively significant coefficient with time trend; however, negatively significant coefficients in Pakistan and Sri Lanka were observed. For maize, results show positively significant results in all countries but Nepal. Similarly, positive but insignificant results are found in case of wheat in all countries.

Table 4: Results of Absolute Yield Variability

Panel A: Rice			
Countries	**α_0**	**α_1**	**R^2**
Bangladesh	57.414 (16.933)***	.888 (.578)	.05
India	116.997 (27.874)***	-.084(.951)	.00[a]
Nepal	77.262 (29.850)**	1.190 (1.019)	.03
Pakistan	476.352 (65.869)***	-9.762(2.248)***	.28
Sri Lanka	232.077(34.679)***	-3.067(1.184)**	.12
Panel B: Maize			
Bangladesh	-1051.091 (314.94)***	73.612 (10.749)***	.49
India	-23.135 (33.592)	8.651 (1.146)***	.54
Nepal	90.414 (16.163)***	-.970 (.552)	.06
Pakistan	-224.898 (99.048)**	17.260 (3.380)***	.35
Sri Lanka	-30.441(73.470)	8.618.(.507)***	.20
Panel C: Wheat			
Bangladesh	195.43740.544)***	.148(1.383)	.00[a]
India	95.176(17.870)***	.030(.601)	.00[a]
Nepal	52.663(21.907)**	.777(.748)	.02
Pakistan	59.328(15.619)***	.590(.533)	.02

Note: values in parentheses are standard errors. '***', '**', and '*' indicate significant at the .01, .05, and .1 levels, respectively and 'a' represents value less than .001.

Additionally, we applied equation (5) to estimate the relative yield variability. Relative yield variability in this study indicates the trend of yield variability with simultaneous consideration of yield growth. We estimated the relative residuals by dividing residual with respective predicted yield. By doing this, increasing residual variability can be offset by increasing the yield level. Results of relative yield variability are presented in panel A, B, and C of Table 6 for rice, maize, and wheat, respectively. As a result, rice yield shows a negatively significant outcome in Bangladesh, India, Pakistan, and Sri Lanka, whereas positive but insignificant in Nepal. In contrast, positively significant results were estimated for maize in Bangladesh, India, Pakistan, and Sri Lanka. However, negative but insignificant results at 0.1 level were seen in Nepal. Likewise, for wheat, results show negative and significant coefficient in Bangladesh, India, and Pakistan.

Table 5: Results of Relative Yield Variability

Countries	α_2	α_3	R^2
Panel A: Rice			
Bangladesh	.040 (.007)***	-.000 [a] (.000) [a]	.03
India	.081(.014)***	-.001 (.000)**, [a]	.10
Nepal	.045(.014)***	.000[a] (.000)[a]	.00[a]
Pakistan	. 213(.028)***	-.005(.001)***	.34
Sri Lanka	.112(.014)***	-.002(.000)***,[a]	.27
Panel B: Maize			
Bangladesh	-.752(.239)***	.055 (.008)***	.49
India	.021(.025)	.005(.001)***	.41
Nepal	.053 (.010)***	-.001 (.000)[a]	.06
Pakistan	-.083(.049)*	.008 (.002)***	.31
Sri Lanka	.039(.060)	.005 (.002)***	.13
Panel C: Wheat			
Bangladesh	.253(.036)***	-.004 (.001)***	.19
India	.111 (.014)***	-.002(.000)** *,[a]	.26
Nepal	.059(.015)***	-.000[a](.001)	.01
Pakistan	.068(.011)***	-.001(.000)**,[a]	.09

Note: values in parentheses are standard errors. '***', '**', and '*' indicate significant at the 0.01, .05, and .1 level, respectively and 'a' represents value less than .001.

Discussion

Yield Trend

We considered the linear model for yield growth estimation in this study. Our results show annual yield growth of rice was about 42, 43, 21, 34, and 43 kg per hectare in Bangladesh, India, Nepal, Pakistan, and Sri Lanka, respectively. The estimated yield growth of rice in South Asian countries is considerably low compared to the global average of 57 kg per hectare (Hafner, 2003). Comparing Hafner (2003) criteria, Bangladesh, India, Pakistan, and Sri Lanka achieved substantial yield growth, whereas only a moderate growth was found in Nepal during the sample period. In case of maize, yields growth in Bangladesh, India, Nepal, Pakistan, and Sri Lanka are about 6, 25, 2, 17, and 13 kg per hectare, which is much lower than the average global growth of 62 kg per hectare (Hafner, 2003). Likewise, Bangladesh, India, Pakistan, and Sri Lanka achieved only moderate growth, whereas Nepal showed no trend.

In case of wheat, quite better results were observed compared to the maize yield. Our estimation results show both better and lower yield performance compared to global yield estimates. In India, the yield grew 47 kg per hectare annually and showed a better performance, whereas in Pakistan (39 kg per hectare), Nepal (22 kg per hectare), and Bangladesh (34 kg per hectare) showed lower performance compared to the global average (43 per hectare) (Hafner, 2003). Moreover, our estimates were substantially lower if compared with Switzerland (75 kg per hectare) (Finger, 2010). The yield growth in Nepal and Pakistan showed moderate and substantial growth, respectively. Importantly, our estimation revealed the interesting outcome from the quadratic model. Out of 14 data sets, 13 revealed significant results at 0.05 or lesser level. Wheat in Bangladesh and India showed a negatively significant result of β_4 and positively significant result of β_3 at .01 level indicating an evidence of slowing growth of yield during the sample period. The results of slowing yield growth can also be clearly seen in the scatter plot diagram (Figure 1). This result is constant with that of Hafner (2003) and Finger (2010), who found the some results of slowing growth in their studies.

Recent literatures depict the evidence of slowing growth or even negative growth of cereal yields in some countries. Calderini and Slafer (1998) presented evidence of leveling off of wheat yields in Mexico. The leveling off of yield in Mexico was started during the 80s by showing the significant results in favor of non increasing yield. In the 90s, some countries in Europe and in the developed world such as USA, Japan, and Canada showed non increasing trends of wheat yield. Moreover, yields in the USSR and Spain showed a negative yield growth. The stated explanation for levelling off yields in those countries was due to the attainment of saturation level. Hafner (2003) analyzed the rice, maize, and wheat yields in 188 countries and revealed 16% data sets with slowing yield growth and decline in some cases. He indicated that two characteristics mostly linked with slowing yield growth are low per capita gross domestic product (GDP) and latitude of the country. Similarly, Finger (2010) analyzed the trends of six cereal yields in Switzerland that showed a slowing growth rate in oat, triticale, and barley. He explained the slowing growth as a cause of policy reform in 1992 in Switzerland. Brisson et al. (2010) explained the climatic and agronomic factors responsible for slowing yield growth of cereals in France.

In our study, slow growth of wheat yield in Bangladesh and India cannot be justified by the same explanation. The most probable influencing factor for slow yield growth of wheat yield in Bangladesh is the comparative disadvantage of wheat with Boro rice. This rice is grown in Bangladesh during the winter season that also coincides with the wheat growing season. Both crops are grown in irrigated and fertile land, thus, are competing each other. However, Boro rice is more profitable compared to wheat but lacks the required investment that is needed for more inputs (Morris et al., 1996; Morris et al.,1997; BARI, 2010). Farmers with less investment capacity do tradeoff between wheat and Boro-rice production. Therefore, farmers allocate more fertile land to Boro rice. As a result, naturally, the productivity of wheat gradually decreased over time. However, government focal programs i.e. in the early 70s and mid 90s showed good achievements towards area coverage and yield of wheat (BARI, 2010). The program of mid 90s continued its momentum till late 90s but could not sustain the achievement for a longer period and yields started to decline after 2000. The highest cropped area for wheat (882224 hectares) was attained in 1999, after that, it started to decline and it reached to 376256 hectares in 2010. The estimation showed the flat region of wheat yield in 2000, after that the yield stated to decline[3]. However, this study characterized the different reasons for slowing yield growth in case of India. This study considered the two possible reasons for slowing wheat yield growth in India. The first one is wheat farming in India is predominated by the rice-wheat system for many years, which depletes the nutrient contents in soils (Ladha et al., 2003). Due to nutrient depletion in soils in the wheat farming area in India, the yield showed the slowing yield growth trends. The second and most important reason is the climate change. The changing trends of temperature and precipitation impacted to decline wheat yield in India (Lobell et al., 2011).

Yield Variability

Some important results have been seen for yield variability analysis of rice, maize, and wheat in South Asian countries. Negatively significant outcomes were observed from absolute yield variation models for rice yields in Pakistan and Sri Lanka indicated decreasing yield variability in those countries. Additionally, relative yield variation results also supported the results of absolute yield variability of rice in Pakistan and Sri Lanka that strongly suggests yield variability in those countries is decreasing over the years. Besides, a significantly negative result of relative yield variability at .05 percent level in India depicts the evidence of rice yield variation is decreasing in India. Thus, by combining both yield variability results, it provides the evidence of rice yield variability is decreasing in India, Pakistan, and Sri Lanka over the years. Our result of decreasing yield variability of rice in India is comparable with the result of Larson et al. (2004) and Ghosh (2010), who suggested the decreasing yield

[3] The trend break was seen in 2000. It shows a negative coefficient with time variable but it is insignificant at .1 level.

variability of rice in India. The reason for decreasing yield variation of rice in India, Pakistan, and Sri Lanka during 1961 -2010 was because of increasing use of modern verities and fertilizer coupled with an increasing rice area under irrigation. Irrigation is a risk reducing input in farming. About 60 percent rice area was under irrigation in India in 2007-2008 (DOAC, 2012), whereas about 76 percent in Sri Lanka in 1009-2010 (DCS, 2012).

In contrast, results are different in case of maize. Positively significant results are found in absolute yield variability model in Bangladesh, India, Pakistan, and Sri Lanka. Similarly, relative yield variability results also support the outcome of the absolute yield variability model that provides a strong indication of increasing yield variability of maize yields for four South Asian countries during 1961-2010. However, in case of Nepal, variability shows negative and insignificant results. Larson et al. (2004) found similar results of yield variability of Maize in India, which is consistent with our result. Past studies indicated that irrigation is a major factor for maize yield variability (Kucharik and Ramankutty, 2005; Rashid and Rasul, 2011). Maize farming is mostly characterized in non-irrigated land in south Asian countries. Therefore, we assumed the maize yields as well as productions are highly influenced by weather shocks in Bangladesh, India, Pakistan, and Sri Lanka.

We find the results of decreasing yield variability in case of wheat in Bangladesh, India, and Pakistan. Although, absolute variability results are negative but insignificant, relative yield variability estimates are highly significant at .01 and .05 level which suggests yield variability is decreasing during the sample period. Our results are consistent with the result of Larson et al. (2004), who presented a result of decreasing wheat yield variability in India. Our results contrast with the results of Finger (2010), who revealed no trends of yield variability for wheat in Switzerland during 1961 to 2006. About 91 percent wheat area in India in 2007-2008 (DOAC, 2012), about 72 percent in Bangladesh in 2005-2006 (BADC, 2012), about 86.5 percent in Pakistan in 2010 (PBS, 2010) was under irrigation. Therefore we characterize the influencing factors for deceasing variation are due to application of improved varieties and better inputs coupled with good irrigation, which may reduce inter annual yield variability in wheat.

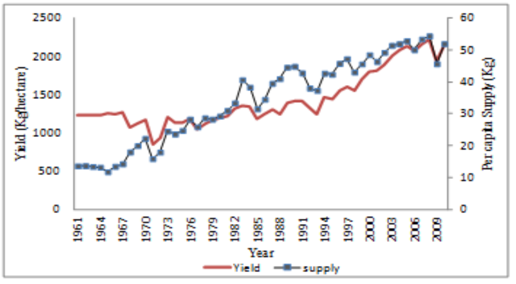
Slow Yield Growth, Yield Variability and Food Security Concern

Area expansion for major cereals is almost saturated in South Asian countries; therefore, increment of production is highly dependent on the yield increment. Consequently, per capita production[4] of particular cereal is dependent on the yield level and growth of population. As we found the slowing growth of wheat yield in two South Asian countries, the study examined the correlation between yield level and per capita wheat supply. All four wheat growing countries show a high correlation i.e. above .8, whereas Bangladesh and India with slowing yield growth of wheat, show the higher correlation of .87 and .95, respectively.

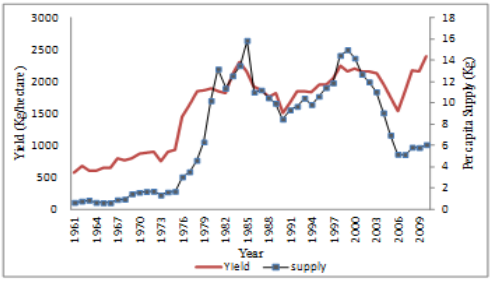
In addition, the relation of wheat yield level and per capita production of wheat is shown in Figure 3. In all countries, as the yield level increases, the per capita food production increases and vice versa. From the previous result, we found the slowing yield growth in Bangladesh and India and it also shows a clear indication of decreasing per capita wheat production in those countries. Per capita wheat production in Bangladesh, India, Nepal, and Pakistan was about 15, 69, 46, and 126 Kg in 1999 and it changed to 6, 66, 52, and 134 Kg, respectively, in 2010. The changes of per capita wheat yield production were about - 63, -4, +13, and +5 percent in Bangladesh, India, Nepal, and Pakistan, respectively, from 1999 to 2010. The results show slowing growth of yield influence in the per capita wheat production as it decreased 63 percent in Bangladesh and 4 percent in India. Consequently, it shows that slow yield growth effects on countries' food

[4] Per capita wheat production is estimated by dividing the total wheat production by the total population of the respective country in the particular year.

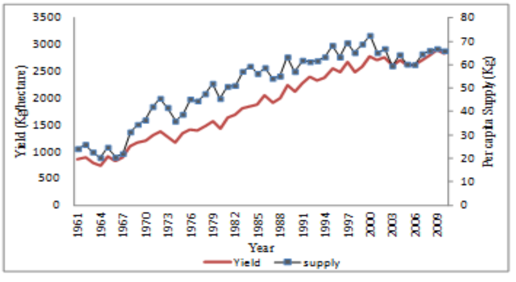
security because wheat importing countries like Bangladesh needs to import more wheat to fulfill country's wheat demand and sufficient quantity producing countries like India depicts a lesser volume of per capita wheat availability.



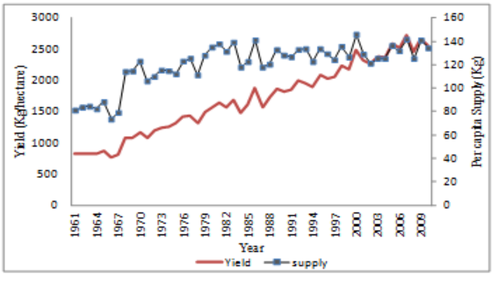
a. Nepal



b. Bangladesh



c. India



d. Pakistan

Figure 2: Yields and per capita production of wheat in Bangladesh, India, Nepal, Pakistan and Sri Lanka (1961-2010)
Source: FAO (2012)

Furthermore, we also examined whether the per capita wheat production decreased significantly in those countries after yield started to decline or slowing growth. Based on the quadratic regression results which showed wheat yield in Bangladesh started to decline from 2001, we split study period in two parts-- the first period (1961 to 2000) and the second period (2001 to 2010). We applied the linear regression model and the results are presented in Table 6. The results in Table 6 indicated that per capita wheat production was increased significantly at .01 level in all countries during 1961 to 2000. Moreover, per capita wheat production was increased significantly at 0.1 level in Pakistan during 2001 to 2010. However, it was decreased significantly in Bangladesh at .01 and increased but insignificant in India and Nepal during 2001 to 2010. The results are as expected because the wheat yield started to decline in Bangladesh since 2001. The yield declining results were severe, therefore, it also significantly influenced to per capita wheat production in Bangladesh. In contrast, the slowing yield growth was not influenced for per capita wheat production in India because the yield growth was only slowed down in this country, which may not impact as greatly as yield decline.

Table 6: Linear Regression results of the Per Capita Wheat Production

Countries	1961 -2000			2001-2010		
	β_0	β_1	R^2	β_0	β_1	R^2
Bangladesh	-1.190(.824)	.398(.035)***	.78	12.711(1.003)***	-.86(.16)***	.78
India	21.643(1.325)***	1.283(.056)***	.93	62.540 (2.038)***	.247(.328)	.06
Nepal	10.219(.982)***	.980(.042)***	.94	49.324 (2.031)***	.254(.327)	.07
Pakistan	91.021(3.784)***	1.295(.161)***	.63	123.340(4.123)***	1.402(.665)*	.35

Since cereals are the sources of staple food, fluctuating production of cereals is highly sensitive to price variation. Yield variation is a major cause of production variation of cereals (Larson et al., 2004). Past studies revealed that price variation is highly influenced by the production fluctuations of the agricultural commodities particularly to the cereals (Shively, 1996). High price level and its variations are one of the challenging factors for food securities specifically to the developing world. As the results revealed increasing yield variability of maize in four countries namely Bangladesh, India, Pakistan and Sri Lanka, which could be quite important for unstable maize price in this region. Therefore, increasing maize yield variability is a challenge for food security in this region.

Conclusions and Policy Implications

South Asia is the most populous and also the highest population growth rate region in the world. Rice, wheat, and maize are the sources of staple food in this region. During the last 60 years, the yields and production of these crops grew tremendously and met the demand for food. However, the past trends should continue to meet the region's future food requirements. Accordingly, the study has examined the yield trends and variability of rice, wheat, and maize, in five South Asian countries.

Rice yield shows a substantial yield growth with more than 33.1 kg per hectare per annum in Bangladesh, India, Pakistan, and Sri Lanka, whereas only moderate growth was found in Nepal. In case of maize, the yield growth was moderate in all 4 countries, but no trend in Nepal. A substantial annual yield growth rate was found in case of wheat in Bangladesh, India, and Pakistan, but a moderate yield growth in Nepal during the study period. Significant and negative coefficients of polynomial in the quadratic model strongly indicate the slowing growth rate of wheat yield in Bangladesh and India. We characterize the explanation for negative yield growth of wheat in Bangladesh as a comparative disadvantage of wheat with Boro rice, which is grown in the same season. In case of India, the dominance of rice-wheat farming system for many years depletes the nutrient content in soil, thereby, slowing down wheat yield growth rate. In addition, a negative impact of climate change was observed on wheat yield growth in India. For more explanation, more studies need to be carried out in sub-national levels considering some possible explaining factors.

A strong decreasing trend of rice yield variability was observed in India, Pakistan, and Sri Lanka. Yield variability in rice depicts that the rice crop benefited from the green revolution technology as well as irrigation over the years. Most importantly, maize yield variation was found positively significant in Bangladesh, India, Pakistan, and Sri Lanka. Low growth but the increasing variability of yield in four major growing countries indicates green revolution technology did not promote maize in this region. Indeed, the main influencing factor of maize yield variation is the domination of rain-fed farming in those countries. Increasing variability along with the low annual yield growth of maize suggests a future problem for food security in this region. Likewise, negative and significant results of wheat present clear indication of decreasing variability of yield in India, Bangladesh, and Pakistan over the years. The main driving factor is the predominance of irrigated land under wheat farming.

Indeed, the slowing growth rate of wheat yield and unstable maize yield can play a significant impact on food security in the respective countries as well as in the region. The analysis indicated the per capita wheat production reduced drastically in Bangladesh while a small reduction was observed in India. Therefore, there is an urgent need to develop a program that can help to revive the yield growth of wheat, particularly in case of Bangladesh. The observed decline in production in Bangladesh was due to decline in both yield and area under cultivation. Consequently, importing countries like Bangladesh need to import additional quantities of wheat grains imported. Thus, provision of high yielding variety seeds along with subsidized inputs can be a good policy to make wheat crop more competitive with Boro rice. This may attract farmers to allocate more land under wheat farming. In case of India, diversification in the cropping systems with the inclusion of legume can be a possible solution. Besides, provision of the special extension program to train farmers to use a balance dose of nutrient could be added advantage. For yield variability of maize, the release of more drought resistant varieties could help to reduce the variability. Effective implementation of a crop insurance based on weather index can be a helpful tool for farmers to protect them from income fluctuation.

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