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Special Topic

Grain yield disparity of rice between tropical and subtropical/temperate regions

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Abstract: Enhancing productivity of rice (*Oryza sativa* L.) is a need to meet the food demand of increasing population. Rice, being the main staple for more than half of the world's population, is grown in a wide range of environments under a variety of climatic conditions covering tropical, subtropical and temperate regions in the world. Some scientists attribute the comparatively higher grain yields of rice in developed countries such as Australia, USA, Japan and China in the

subtropical/temperate region to the technological improvements, without disclosing precise technological gaps for yield disparity, while ignoring the influence of climatic- and soil-related differences of the regions. Studying the influence of climate and soil characteristics on rice yield disparity between tropical and temperate/subtropical regions is important to avoid erroneous conclusion given in explaining any yield disparities. Existing grain yield disparity of rice between the two regions can mainly be attributed to environmental factors such as incident solar radiation, temperature and soil fertility, but not to the improved technology. In Sri Lanka, the influence of technological advancements on the grain yield resulting in yield disparities compared to other developed countries as indicated by some critics, is irrelevant and invalid owing to confounding effects of the environmental factors. If a fair comparison to be made on grain yield disparity of rice between countries, they have to be within the same region, *i.e.* tropical or subtropical/temperate, where the climatic- and soil-related factors are fairly uniform.

Keywords: Grain yield disparity, rice, subtropical/temperate and tropical environment, technological gap



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Introduction

Rice (*Oryza sativa* L.) is the main staple for more than half of the world's population (Macleay *et al.*, 2002) and global rice demand is estimated to be 852 million tons by 2035 (Khush, 2013). As expansion of cultivated area and increase in annual cropping intensity are limited, the only viable and sustainable option left to increase rice production is to enhance rice productivity (yield per unit land area) to meet the food demand of increasing population. The productivity of any crop at farmer level is dependent upon the yield potential,

potential yield and the crop management practices. Yield potential is the genetic potential, which is dependent on biological or plant factors under the ideal environmental conditions whereas potential yield is the yield of a variety × environment combination under the best crop management in that environment. The yield potential of a crop variety differs from environment to environment depending on the temperature and solar radiation regimes and related soil factors (Abeysiriwardena, 2016).

Rice is grown in a wide range of environments under a variety of climatic conditions (Global Rice Science Partnership, 2013) from the equator to about 53°N and 40°S and at elevations ranging from below sea level to 2700 m amsl (FAO Rice Information, 2000) covering tropical, subtropical and temperate regions in the world. Potential yield of rice varies among rice growing environments although the theoretical or maximum yield potential of rice has been estimated to be 23.8 t/ha of rough rice at 14% grain moisture content (Abeyasiriwardena, 2016). In general, if the potential yield is high in a given environment, the yield realized at farmer level will also be higher in all environments with a yield gap between potential and realized yield, which varies depending on the environment and cultivation practices adopted. Such information should be used when grain yield comparisons of rice are made among rice-growing countries in different climatic regions to avoid generation of any misleading information. In the recent past, it has been observed that some agricultural as well as non-agricultural professionals are attributing the higher grain yields of rice achieved in developed countries such as Australia, USA, Japan and China, than that of developing countries such as Sri Lanka, India, Philippines and Thailand, totally to the improved

Rice yield disparity

Agricultural yields for all crop categories are lower in the tropics than in temperate region (Gallup and Sachs, 2000). Rice is the main agricultural crop in most of the tropical countries, however, it is also grown in countries in the subtropical/temperate region. The average rice grain yields per season and number of cropping seasons cultivated per year in tropical and subtropical/temperate countries in 1960's, 1997 and 2019 are presented in Table 1. As reported by Rosenzweig and Liverman (1992), Table 1 shows that the average rice grain yields per season in the subtropical/temperate region are always much higher than that of tropical region from the past to the present. In general, the number of cropping seasons per year in subtropical/temperate region is one and in the tropical region is two. The cropping season in subtropical/temperate region are longer than that of individual cropping seasons in the tropics. Rice Production Manual (1970) also reported that the national average rice yield per unit land area (t/ha) in the tropics have

technologies and technological gaps between countries as a factor contributing to such yield disparities. Though confounded with technological advancements, influence of climate and soil characteristics between those developed and developing countries on rice yields have totally been ignored.

The countries namely USA, Australia, Japan and China are having temperate/subtropical climate while countries namely Sri Lanka, India, Philippines and Thailand are having tropical climate. The rice plant's environments have been divided into several agro-ecological regions by FAO where tropics are the areas with monthly mean temperature of > 18 °C for all months, subtropics with monthly mean temperature of < 18 °C for one or more months, and temperate areas are with monthly mean temperature of < 5 °C for one or more months (Maclean *et al.*, 2002). Thus, studying the rice yield disparity between tropical and temperate/subtropical regions and the influence of climatic and soil related factors between those regions on yield disparity would be of paramount importance to refrain from misconceptions in explaining the so called yield disparity in relation to productivity improvement.

traditionally been considerably lower than the average rice yields obtained in subtropical/temperate zone countries.

Grain yield of single-season rice crop in the subtropical environment was significantly higher than that of double-season rice crop in the tropical environment (Ying *et al.*, 1998). Even the grain yield of double-season rice crop in the subtropics was 9-66% higher than that of in the tropics (Wang *et al.*, 2016). Very high rice grain yields of 13-16.5 t ha⁻¹ has been reported in the subtropical environment in China (Ying *et al.*, 1998; Katsura *et al.*, 2008) and in the temperate environments in Australia (Williams, 1992). The highest rice yield recorded to-date under subtropical environment is 17.1 t ha⁻¹ (Yuan, 1998) and under tropical environment is 11.73 t ha⁻¹ (Emitiyagoda *et al.*, 2010).

Table 1. Rice grain yields per season and number of cropping seasons cultivated per year in tropical and subtropical/temperate countries in 1960's, 1997 and 2019.

Climatic Region	Country	Number of cropping seasons/year	Grain yield (t/ha/season)		
			1960's	1997	2019
Subtropical/temperate	Australia	1	5.91	8.72	8.77
	China	1	3.91	6.29	7.05
	Egypt	1	NA	8.16	8.37
	Greece	1	NA	7.93	7.39
	Japan	1	5.24	6.19	6.82
	Korea (Republic)	1	3.90	6.31	6.87
	Italy	1	5.12	5.81	6.78
	Mexico	1	2.72	4.70	6.36
	Spain	1	6.34	6.87	7.53
	USA	1	4.44	7.13	8.37
		Average		4.69	6.81
Tropical	Bangladesh	2	NA	2.79	4.73
	Cambodia	2	1.48	1.73	3.62
	Cuba	2	NA	2.72	3.48
	Ghana	2	NA	2.20	2.88
	India	2-3	1.54	2.83	4.05
	Indonesia	2	1.96	4.39	5.11
	Malaysia	2	2.37	3.12	4.25
	Myanmar	2	1.56	3.21	3.79
	Nepal	1	1.98	2.45	3.76
	Nigeria	2	NA	1.60	1.59
	Pakistan	1	1.65	2.88	3.66
	Philippines	2	1.25	2.89	4.04
	Sri Lanka	2	NA	3.95	4.79
	Thailand	2	1.61	2.25	2.91
	Average		1.70	2.77	3.75

NA - Indicate data not available; Sources – Rice Production Manual (1970); FAOSTAT (various years); Ngyun and Tran (2000)

Reasons for the yield disparity

Performance of any crop species/genotype results from its interaction with the environment that it is exposed to. Rice is not an exception to this phenomenon. The crop environment is composed of biotic (insect pests, weeds and diseases) and abiotic (climate and soil) components. The potential yield of rice in a given environment is basically determined by climate and soil and the proper insect pest, weed and disease management would allow the crop to sustain the potential.

The sink size or the number of spikelets per m² is the primary determinant of grain yield in cereal crops grown without stresses. The sink size is also highly related to dry matter accumulation from panicle initiation to flowering (Kropff *et al.*, 1994), whereas grain filling largely depends on biomass accumulation from flowering to maturity (Yoshida,

1981). Finally, the yield is dependent on increased biomass production. The biomass production can be increased by increasing growth duration or crop growth rate (CGR) or both (Yoshida, 1983). The CGR is a function of canopy gross photosynthesis and crop respiration (Evans, 1993). Respiration is strongly influenced by temperature (Akita, 1993) while solar radiation and temperature are influencing canopy photosynthesis (Loomis and Connor, 1992).

The sink size and biomass production are responsible for the yield difference between the tropical and subtropical/temperate environments (Ying *et al.*, 1998; Wang *et al.*, 2016). Each of the sink size and biomass was 50% higher in the subtropical environment than that of in the tropics. Temperate/subtropical region is blessed with soil and climatic factors optimal for rice cultivation with a comparatively much higher grain yields than that

of tropical region where soil and climatic factors are non-optimal for rice cultivation. The low rice yields common through the tropics are probably the net result of many factors, some of which are high day and night temperatures, low light intensity and high rain fall (Rice Production Manual, 1970). Same set of modern cultivars when grown in subtropical and tropical climates have given grain yields of 11.3 and 8.5 t/ha, respectively, due to about 50% more biomass production in the subtropics than in the tropics owing to relatively longer growth duration and higher CGR in subtropics (Ying *et al.*, 1998). In addition, soils in the humid tropics are unproductive (Synthia and Diana, 1992). Thus, the main factor that appears to influence the grain yield disparity of rice between temperate/subtropical and tropical countries is the environment, including the level of incident solar radiation, temperature and soil fertility, but not the difference in improved technology.

Level of incident solar radiation:

Incoming solar radiation takes the forms of direct radiation and diffused sky radiation. The sum of these two is called global radiation or incident solar radiation. In the tropics and in the temperate regions, rice yield per hectare is primarily determined by the incident solar radiation (Yoshida, 1981). It is generally believed that comparatively higher grain yield is associated with higher incident solar radiation and higher intercepted solar radiation by rice crop canopy as the crop canopy photosynthesis is largely driven by the intercepted solar radiation during the growing season (Katsura *et al.*, 2008).

'High yields of rice in subtropical and temperate environments is mainly due to longer growth duration and greater solar radiation', is a generally accepted fact and longer growth duration is linked with greater biomass production and consequently greater grain yield. The highest rice yields have traditionally been obtained from plantings in high-latitude areas that have long day lengths or in low-latitude desert areas that have very high solar energy levels (Maclean *et al.*, 2002).

A major factor that determines crop productivity in two regions is the difference in photoperiod (day length), which influence on photosynthesis, *i.e.* the net assimilation rate after allowing respiratory losses. A photoperiod of 14 hr/day delays flowering even in the photoperiod insensitive varieties

compared to 12 hr/day, and the longer photoperiod may also contribute to longer vegetative and reproductive phases in rice (Ying *et al.*, 1998). In modern rice varieties cultivated in both regions, plant canopy structure is designed to improve photosynthetic efficiency while containing respiratory losses. The so-called high potential countries in the subtropical/temperate region do cultivate only one crop a year (Table 1) and the cropping season is determined when the temperature is conducive and photoperiod is almost above 13 hr/day. Photoperiod reaches its maximum (around 16 hr/day) when the crop is in its reproductive phase and crop, too, takes more than four months to mature in the field. In contrast, rice is generally cultivated over two seasons per year in the tropics and photoperiod for the whole year is around 12 hr/day. This results in that the crop duration in the tropics is always shorter than that of in the subtropical/temperate environment. Ying *et al.* (1998) reported that the total growth duration from sowing to maturity was 32 to 58 days longer under the subtropical climate in Yunnan, China than under the tropical climate at IRRI, Philippines, depending on varieties. Tropical rice crop eternally suffers this disadvantage of photoperiod difference between tropical and subtropical/temperate regions.

Rice yield is primarily determined by the level of incident solar radiation (Evans and De Datta, 1979; Yoshida, 1981). However, crop biomass production is a function of the seasonal accumulation of solar radiation and radiation use efficiency (RUE) (Monteith, 1977). Higher biomass production and the higher grain yield in the subtropical environment is due to higher RUE compared with the tropical environment (Wang *et al.*, 2016). Although a single season crop in the subtropical/temperate environment is giving higher yields than double season crop in the tropical environment, higher yield can also be attained in double season rice crop in subtropical/temperate environment than that of in tropical environment and this can be attributed to comparatively higher RUE in double season rice crop in the subtropical/temperate environment (Wang *et al.*, 2016). The RUE can be affected by variety, nitrogen management and climatic condition (Katsura *et al.*, 2007; Zhu *et al.*, 2008). Under conditions where the adapted varieties are used with best management practices in both environments, higher RUE in the subtropical environment is associated with the lower

temperature compared with the tropical environment (Wang *et al.*, 2016).

Temperature:

Temperature is one of the most important climatic factors that influence on plant growth and yield of rice. The annual temperature in the temperate region, exceeds the daily temperature range but in the tropics daily temperature range is greater than the annual range (Yoshida, 1981). Thus in temperate region, only one rice crop can be cultivated a year and the cropping season is determined when the temperature is conducive for the rice crop. However, in the tropics rice can be grown throughout the year. Low rice yields in the tropics is undoubtedly and partially due to the warm climate where for every 10 °C rise in temperature, respiration rate increases twice as fast as the photosynthetic rate (Rice Production Manual, 1970). Similarly conducive cool temperature in the temperate/subtropical region results in high rice yields. The warm tropical climate has been considered as a factor responsible for low rice yields as net dry matter production is inevitably lower under higher temperatures due to increase in respiratory losses (Yoshida, 1981). Rice grain yield declined by 10% for each 1 °C increase in minimum temperature in the growing season under the irrigated conditions in the tropics (Peng *et al.*, 2004).

Grain yields of rice tend to be higher in areas where the temperature following flowering is low. Higher temperature during the ripening period in rice causes a higher rate of respiration and an unfavourable balance between photosynthesis and respiration. Plant maintenance respiration increases with increasing temperature (Amthor, 2000). Higher maintenance respiration reduces the amount of assimilates available so that the growth and yield are reduced (Monteith, 1981). In addition, lower temperature during the ripening period not only favours low respiration but also increases the length of ripening period exposing the rice crop to a greater amount of total solar radiation resulting in a higher grain yield. In many areas higher grain yields have been obtained when the ripening period is long (Rice Production Manual, 1970).

There was a large effect of temperature on rice grain yield when solar radiation and crop growth duration were not confounding factors for explaining yield difference between the tropical and subtropical environments. This was because of

higher radiation use efficiency (RUE) associated with the lower temperature in subtropics compared to significantly reduced RUE associated with high temperature in the tropics (Wang *et al.*, 2016). In addition, temperature appears to be a major climatic factor that influence the efficiency at which nitrogen produces spikelets and the efficiency of nitrogen use in producing spikelets is higher in cooler northern Japan than in warmer southern Japan suggesting that cooler climate favours higher nitrogen use efficiency (Yoshida, 1981).

Soil fertility:

One causal factor for higher rice grain yields in subtropical/temperate region than that of in tropical region is comparatively higher soil fertility in the subtropical/temperate region (Rosenzweig and Liverman, 1992). Irrespective of the parental material involved in the genesis, soils in the tropics are leached by heavy monsoon rains and therefore less fertile; particularly the rice soils are subjected to intensive and continuous double cropping without a resting or fallow period for replenishment. Furthermore, the consistent soil microbial activity caused by high temperature regimes in the tropical region decomposes the organic matter rapidly affecting physical, chemical and biological properties unfavourably particularly the cation exchange capacity (CEC). Due to slow microbial activity resulting from low temperature regimes, soils in the temperate region are fertile, rich in organic matter content and CEC. On an average, soil carbon turnover is twice as fast as in tropics compared with temperate region and feedback between soil organic matter and aggregation is less tight in tropics than in temperate soils (Six *et al.*, 2002).

Soil organic carbon (SOC), humic acid carbon (HAC), fulvic acid carbon (FAC), humin carbon (HUC) and extractable humus carbon (HEC) levels increase with increasing latitude and exhibit a general trend of tropical < subtropical < temperate climates. More than 90% of this latitudinal variation in SOC, HAC, FAC, HUC and HEC can be explained jointly by climate, soil temperature and soil microbes (Xu *et al.*, 2018). Nutrient surplus is a major concern in many temperate soils under agriculture, whereas the increase in soil fertility is an important research topic in the tropical region (Hartemink, 2002). For example, Australian rice soils in the temperate regions are rich in native

fertility and sometimes application of nutrients P and K is not needed for rice production.

Improved technology

Variety potential and/or technological gap are utterly irrelevant and invalid in explaining grain yield disparity of rice between subtropics/temperate and tropical regions. Rice grain yields of 13-16.5 t ha⁻¹ (Ying *et al.*, 1998; Katsura *et al.*, 2008; Williams, 1992), which are closer to the potential yield of 17.113 t ha⁻¹ (Yuan, 1998) that has been reported in China and Australia in the subtropical/temperate environment, while under tropical environment rice grain yield of 10-11.47 t ha⁻¹ (Emitiyagoda *et al.*, 2010; De Datta, 1981) which are closer to the potential yield of 11.73 t ha⁻¹ under tropics (Emitiyagoda *et al.*, 2010) have been reported from Sri Lanka and the Philippines. This indicates that improved technology to attain rice grain yields closer to respective potential yields are available in both subtropics/temperate and tropical regions. Grain yield difference between two regions is mainly dependent on the difference in potential yield, which is solely dependent on climatic and soil environment but not on any technological gap.

Sri Lanka where the staple food is rice, can be taken as an example to show how technology improvement over time has influenced to increase grain yield of rice in a country in the tropical environment. In Sri Lanka, national average rice yield has gradually increased from about 0.65 t ha⁻¹ in 1940's through 3.70 t ha⁻¹ in 1990's to 4.85 t ha⁻¹ in late 2019 and the main reason for this yield improvement is the development of improved technology mainly in the areas of variety development, fertilizer management and agronomic practices to attain the potential yield and proper pests and disease management to sustain the potential (Abeywardena, 2000; Weerakoon *et al.*, 2017; Dhanapala *et al.*, 2020). In some stable and high potential environments, a yield of 10.0 t ha⁻¹ approximating the potential of the varieties, is not uncommon despite overall average performance is low. The inconsistent yield

by any variety within the country is attributed to the effect of specific agro-ecological environments but not to the inadequacy of available technology as potential yield varies among agro-ecological environments. Technology is available to obtain high grain yields close to the potential in high potential areas. Emitiyagoda *et al.* (2010) has reported 10-11.73 t ha⁻¹ of grain yield of rice in 24 locations in the high potential areas in Sri Lanka using an improved package of management with improved varieties.

Fair comparison

Level of incident solar radiation, temperature and soil fertility explain the grain yield disparity in rice between countries in the tropics and countries in the subtropics/temperate region. Influence of technological advancement on the so called grain yield disparity in rice as indicated by some critics is remote. Any critic can evaluate popular improved high yielding Japonica rice varieties, namely, *Koshi-hikari*, *Akitakomachi*, *Reiho*, etc. or the Australian counterpart; Calrose, Ingra, Blue-bonette, Blubelle, etc. or any other known advanced technology package used in subtropics/temperate region under the tropical environment and verify how they perform. The results will convince that it is not the variety or technology but the crop environment that is the deciding factor of yield disparity between the two regions.

If a fair comparison is made on grain yield disparity of rice between countries, they have to be within the same region; tropical or temperate, where the climatic and soil factors are fairly uniform. For example, if national average rice yield of Sri Lanka is compared with that of other countries in the tropical region, Sri Lanka is falling behind Indonesia only but all the other countries including India, Philippines, Thailand and Cuba are falling behind Sri Lanka. Similarly, if national average rice yield of Australia is compared with that of other countries in the subtropical/temperate region, Australia is recording the highest yield while all the other countries including USA, Japan and China are falling behind Australia (Table 1).

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