NJAS - Wageningen Journal of Life Sciences xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

The solar radiation-related determinants of rice yield variation across a wide range of regions

Min Huang*, Shuanglü Shan, Fangbo Cao, Yingbin Zou

Southern Regional Collaborative Innovation Center for Grain and Oil Crops (CICGO), Hunan Agricultural University, Changsha 410128, China

ARTICLE INFO

Article history:
Received 15 June 2015
Received in revised form 4 May 2016
Accepted 9 May 2016
Available online xxx

Keywords:
High yield
Radiation use efficiency
Rice
Solar radiation

ABSTRACT

The information available on the environmental and plant characteristics that contribute to rice yield variation over a wide range of regions would be useful for understanding the generalized determinants of rice yield. In this study, we extracted the data ($n = 107$) of grain yield, biomass production, harvest index, intercepted radiation, radiation use efficiency (RUE), incident radiation and intercepted percent from 5 published studies conducted in 6 locations across 3 countries and evaluated the relationships between the parameters. A very large variation in grain yield, from 3.31 to 16.50 t ha^{-1}, was observed. About 73% and 6% of the yield variation was explained by biomass production and harvest index, respectively. Biomass production was strongly positively related to intercepted radiation. However, intercepted radiation would be difficult to further increase because it was related much more closely to incident radiation than to intercepted percent. Although RUE did not explain the variation in biomass production, it varied by nearly two fold (0.99–1.88 g MJ^{-1}). Our study highlights the need for a comprehensive understanding of the various aspects of RUE in rice.

1. Introduction

Rice is the main staple crop for a large segment of the world population [1]. It is grown widely in South and Southeast Asia with more discrete regional distribution in Southern Europe, Southern U.S., South America, Middle East, and Africa [2], covering 163 million ha in 2012 (http://faostat.fao.org/). Rice yield has undergone two quantum leaps with the development of semi-dwarf and hybrid cultivars [3]. However, in the past few years, the growth of rice yield has dropped below 1% per year worldwide, whereas a rice yield increase of more than 1.2% per year is required to meet the growing demand for food that will result from rapid population growth and economic development [4]. Therefore, it is urgent to identify the ways in which a further yield improvement can be achieved in rice.

Rice yield can be increased by increasing biomass production or harvest index or both [5], but there have been increasing reports suggesting that achieving greater rice yields mainly depends on increasing biomass production [6–9]. Biomass production is the product of intercepted solar radiation by the canopy and radiation use efficiency (RUE, i.e. biomass produced per unit of radiation intercepted), and the former is determined by incident solar radiation and intercepted percent (i.e. fraction of incident radiation intercepted by the canopy) [10]. It is well known that incident radiation is related to growth duration, while intercepted percent is dependent on canopy morphological characteristics such as leaf area, angle and orientation [6,8,10]. But in fact, there is little interest in prolonging growth duration because the current durations coincide with suitable seasons or allow multiple cropping in a year [11], and it is difficult to improve canopy morphology because most high-yielding cultivars are close to the optimum canopy architecture [12,13]. Therefore, increasing intercepted radiation may be not a feasible way to further increase biomass production and grain yield in rice. Also, because of this, it is reported that increasing RUE may be the only way for achieving a substantial increase in rice yield [11].

Cross-location analysis is a useful approach for determining the environmental and plant traits that contribute to high yields. However, previous cross-location analyses on rice yield attributes were usually conducted in 2 or 3 locations [6,14,15], and the results obtained from these studies might be limited by the specific environmental conditions (climate and soil), cultivars and agronomic practices. Therefore, more studies on a wider range of regions are needed to draw a concrete conclusion on the generalized determi-

* Corresponding author.
E-mail address: jxhuangmin@163.com (M. Huang).

http://dx.doi.org/10.1016/j.njas.2016.05.004
1573-5214/

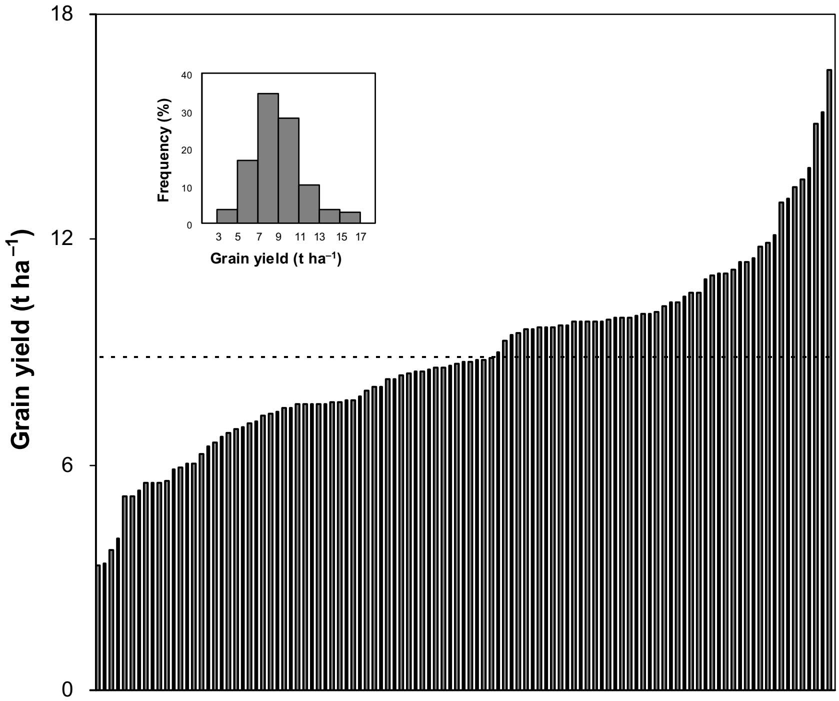

Fig. 1. Grain yield in rice crops across a wide range of regions. Data ($n = 107$) were extracted from the selected articles. The horizontal dot line represents the average of the data. The inset shows a frequency histogram of the data.

nants of rice yield. In the present study, we analyzed relationships between yield attributes with solar radiation interception and utilization in rice crops by using data extracted from 5 published studies conducted in 6 locations across 3 countries. Our objective was to understand the solar radiation-related determinants of rice yield variation over a wide range of regions.

2. Materials and methods

A literature search was performed in the Google Scholar database (scholar.google.com) using the keywords "rice", "solar radiation", "radiation interception", and "radiation use". Five articles were selected for which following the criteria applied: (1) tested crop was rice, (2) experiments were conducted under field conditions, and (3) data of grain yield, aboveground total biomass, harvest index, intercepted radiation, RUE (aboveground total biomass/intercepted radiation), incident radiation and intercepted percent (intercepted radiation/incident radiation ×100) were available or derivable from the available data. Detailed information about field experiments in the selected articles is given in Table 1. Briefly, the experiments were conducted in Ina and Kyoto of Japan, Yanco of Australian, and Taoyuan, Liuyang and Guidong of China during 1989–2011. Eighteen cultivars were used in the experiments. In each experiment, rice plants were grown under diverse agronomic practices, such as N application. From the selected articles, a total of 107 data points was extracted for each above-mentioned parameter. The relationships between the parameters were evaluated by using linear regression with Statistix 8.0 software (Tallahassee, FL, USA).

3. Results

Among the selected articles, a wide range of variation in grain yield, from 3.31 to 16.50 t ha^{-1}, was observed, with a mean of 8.86 t ha^{-1} (Fig. 1). Also, there were large variations in other above-mentioned parameters (Fig. 2a–f). Biomass production varied from 443 to 2752 g m^{-2} and averaged 1547 g m^{-2}; harvest index ranged from 0.25 to 0.61, showing a mean of 0.50; intercepted radiation varied from 365 to 2566 MJ m^{-2}, with an average of 1104 MJ m^{-2}; RUE ranged from 0.99 to 1.88 g MJ^{-1} and averaged 1.42 g MJ^{-1}; incident radiation varied from 1109 to 3233 MJ m^{-2}, showing an average of 1671 MJ m^{-2}; and intercepted percent ranged from 33% to 79%, with a mean of 66%.

There were significant positive relationships between grain yield with biomass production ($p < 0.0001$) and harvest index ($p < 0.01$; Fig. 3a and b). Grain yield was related much more closely to biomass production than to harvest index; about 73% and 6% of the variation in grain yield was explained by biomass production and harvest index, respectively. Biomass production was strongly positively related to intercepted radiation ($p < 0.0001$) but not to RUE ($p = 0.51$; Fig. 3c and d). Close positive relationships were detected between intercepted radiation with incident radiation ($p < 0.0001$) and intercepted percent ($p < 0.0001$; Fig. 3e and f). Incident radiation had more power to explain the variation in intercepted radiation (73%) than intercepted percent (36%).

4. Discussion

There is considerable variation in rice yield across regions that results from many factors including environmental conditions, cultivars and agronomic practices [3] and is difficult to assess the determinants of the variation in a single study. In the present study, we pooled the data of 5 published studies done in 6 locations across 3 countries with various cultivars and agronomic practices. A very large variation in rice yield (3.31–16.50 t ha^{-1}) was observed, and more than 70% of the yield variation was accounted for by the variation in biomass production. This result again confirms that achieving greater rice yields mainly depends on increasing biomass production [6–9].

Biomass production can be increased by increasing intercepted radiation or RUE or both. In the present study, the biomass production variation was explained by intercepted radiation but not

Please cite this article in press as: M. Huang, et al., The solar radiation-related determinants of rice yield variation across a wide range of regions, NJAS - Wageningen J. Life Sci. (2016), http://dx.doi.org/10.1016/j.njas.2016.05.004