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Short note

Raising potential yield of short-duration rice cultivars is possible by increasing harvest index

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Description of the subject. Further increases in rice yield potential are generally thought to require greater biomass assimilation. This study presents a new cultivar that draws greater yield from increased harvest index (HI).
Objectives. Our objective was to identify the physiological traits that are critical to the high yield of a recently developed short-duration rice cultivar Guiliangyou 2 (GLY2).
Method. GLY2 and a check cultivar Yuxiangyouzhan (YXYZ) were grown in a field at the Experimental Farm of Guangxi University, Guangxi province, southern China in early and late rice-growing seasons in 2013. Grain yield, yield components, canopy characteristics including leaf area index (LAI), leaf N content (LNC), leaf area duration (LAD) and assimilation rate (NAR), biomass accumulation, and harvest index were determined for each cultivar in each season.
Results. GLY2 produced 17–38% higher grain yield than YXYZ with the same growth duration. Spikelets per m^2 and grain weight were higher in GLY2 than in YXYZ by 11–13% and 6–17%, respectively. GLY2 had higher LAI and LAD but lower LNC and NAR than YXYZ. As a consequence of the compensation between the canopy characteristics, there was no significant difference in biomass accumulation between the two cultivars. Harvest index of GLY2 was 13–23% higher than that of YXYZ. Large sink size, high remobilization of stored reserves and maintained biomass production after heading were responsible for the high HI of GLY2.
Conclusions. Our study suggests that it is possible to increase HI together with grain yield by improving the potential sink size and the remobilization of stored reserves while maintaining high LAI and LAD in short-duration rice.
Keywords. Rice, life cycle, agronomic characters, leaf area index, harvest index, crop yield.

Augmenter le potentiel de rendement de variétés de riz de cycle court est possible par l’augmentation de l’indice de récolte

Description du sujet. Des augmentations du potentiel du rendement de riz sont généralement associées à une plus grande assimilation de la biomasse.
Objectifs. L’objectif de cette étude était d’identifier les caractéristiques physiologiques d’un cultivar de riz de cycle court Guiliangyou 2 récemment développé par l’Académie des Sciences Agricoles de Guangxi en Chine qui sont essentielles pour l’obtention d’un rendement élevé.
Méthode. Le cultivar Guiliangyou 2 (GLY2) et un cultivar Yuxiangyouzhan (YXYZ) ont été cultivés en champ à la ferme expérimentale de l’Université de Guangxi, province du Guangxi, au sud de la Chine au cours des saisons rizicoles précoces et tardives en 2013. Le rendement en grains, les composantes du rendement, les caractéristiques des plantes, y compris l’indice de surface foliaire (LAI), le contenu de la feuille en N (LNC), la durée de surface foliaire (LAD), le taux d’assimilation (NAR), l’accumulation de la biomasse et l’indice de récolte ont été déterminés pour chaque cultivar au cours de chaque saison.
Résultats. Le cultivar GLY2 montre un rendement en grains de 17 à 38 % supérieur à celui du cultivar YXYZ avec la même durée de croissance. Le nombre d’épillets par m^2 et le poids des grains étaient plus élevés respectivement de 11 à 13 % et de 6 à 17 % pour GLY2. GLY2 avait un LAI et un LAD supérieurs mais un NAR et LNC inférieurs à YXYZ. La compensation entre les caractéristiques des plantes s’est traduite par l’absence de différence significative de l’accumulation de la biomasse entre les deux cultivars. L’indice de récolte de GLY2 était de 13 à 23 % supérieur à celui de YXYZ. La grande taille des

organes de stockage, la haute remobilisation des réserves stockées et la production de biomasse maintenue après l'épiaison sont responsables de l'indice de récolte élevé obtenu pour GLY2.

Conclusions. Notre étude suggère qu'il est possible d'augmenter l'indice de récolte ainsi que le rendement en grains par l'amélioration de la taille potentielle des organes de stockage et la remobilisation des réserves stockées tout en maintenant un LAI et un LAD élevés pour le riz de cycle court.

Mots-clés. Riz, cycle de développement, caractère agronomique, indice de surface foliaire, indice de récolte, rendement des cultures.

1. INTRODUCTION

The availability of short-duration rice cultivars has led to large increases in cropping intensity, greater on-farm employment, increased food supplies and higher food security in many major rice-producing countries (Khush, 2001). However, the scope for a further increase in cropping intensity is limited because annual double-rice systems are now the dominant cropping system where soil, climate, and water allow intensified cropping (Cassman, 1999). Meanwhile, the rapid population growth and economic development have been posing a growing pressure for increased food production (Zhang, 2007). According to various estimates, world rice production must increase at the rate of 2 million tons per year (Jeon et al., 2011). To achieve this goal, great efforts should be made to breed new short-duration rice cultivars with higher yield for intensive rice systems.

Rice yield is determined by spikelet number per unit land area, spikelet filling percentage and grain weight. The spikelet number per unit land area is considered as the primary determinant of the rice yield (Kropff et al., 1994). In another approach, rice yield is a function of biomass production and harvest index (HI). Evans et al. (1984) reported that rice yield difference between traditional and modern cultivars was due to difference in HI. But when comparison was made among the modern rice varieties, high rice yield was achieved by increasing biomass production (Akita, 1989). Evans et al. (1999) further stated that achieving higher rice yield depended on increasing the biomass production, because there was little scope to further increase HI. Peng et al. (1999) also suggested that further improvement in the rice yield might come from an increase in biomass production rather than in HI. Biomass production is closely related with canopy characteristics, such as leaf area index (LAI), leaf N content (LNC), leaf area duration (LAD) and net assimilation rate (NAR) (Kropff et al., 1993; San-oh et al., 2004; Ibrahim et al., 2013).

Guiliangyou 2 (GLY2) is a short-duration rice cultivar (F_1 hybrid) developed by the Guangxi Academy of Agricultural Sciences of China with Guike-2S as the female parent and Guihui 582 as the male parent using the two-line method. Guike-2S is a photo-thermo-sensitive genetic male sterile line and belongs to *indica*. Guihui 582 is an *indica* restorer line. In the rice regional trials of Guangxi Province in 2006 and 2007, GLY2 produced about 8% higher grain yield than the check cultivar. Consistent results were also observed in the on-farm rice production trials. Consequently, GLY2 was released in Guangxi Province in 2008 and approved as "super rice" by the National Ministry of Agriculture in 2010. In our current study, we compared GLY2 with a widely grown cultivar with comparable growth duration. Our objective was to identify the physiological factors that are critical to the high yield of GLY2.

2. MATERIALS AND METHODS

Field experiments were conducted at the Experimental Farm of Guangxi University (22°51' N, 108°17' E, 78 m a.s.l.), Guangxi province, southern China in early and late rice-growing seasons in 2013. The site is located in a subtropical monsoon climate zone, with a mean annual temperature of 22.4 °C, a mean annual precipitation of 1,174 mm, and a mean annual sunshine of 1,668 h. The soil of the experimental field was classified as Fe-leachi-Stagnic Anthrosols (CRGCST, 2001); it had the texture of clay loam with pH = 6.75, organic matter = 32.3 $g \cdot kg^{-1}$, NaOH hydrolysable N = 120 $mg \cdot kg^{-1}$, Olsen P = 31.6 $mg \cdot kg^{-1}$, and NH_4OAc extractable K = 126 $mg \cdot kg^{-1}$. The soil test was based on samples taken from the upper 20 cm of the soil.

Yuxiangyouzhan (YXYZ), an inbred cultivar developed by the Guangdong Academy of Agricultural Sciences of China in 2005, was chosen as the check cultivar because it has been widely grown in southern China and has similar growth duration as GLY2. In each season, GLY2 and YXYZ were arranged in a randomized complete block design with three replications and plot size of 25 m^2. Pre-germinated seeds were sown in a seedbed. Twenty-day-old seedlings were transplanted on 29 March and 13 August in early and late seasons, respectively. Transplanting was done at a hill spacing of 20 cm × 20 cm with two seedlings per hill. Fertilizers used were urea for N, single superphosphate for P and potassium chloride for K at rates of 150 kg $N \cdot ha^{-1}$, 75 kg $P_2O_5 \cdot ha^{-1}$ and 150 kg $K_2O \cdot ha^{-1}$. Nitrogen was split-applied: 75 kg·

ha^{-1} at basal (1 day before transplanting), 45 $kg \cdot ha^{-1}$ at early tillering (7 days after transplanting), and 30 $kg \cdot ha^{-1}$ at panicle initiation. Phosphorus was applied at basal. Potassium was split equally as basal and top dressing at the panicle initiation. The experimental field was flooded from 4 days after transplanting until 7 days before maturity. Pests and weeds were controlled using chemicals to avoid yield loss.

Eight hills were sampled from each plot at 45, 60, 75 and 90 days after transplanting in early season and at 35, 50, 65 and 80 days after transplanting in late season. Fully expanded green leaves were removed from plants and leaf area was determined by the length-width method (Umashankar et al., 2005) and expressed as LAI. Each plant organ was oven-dried at 70 °C to constant weight to determine biomass. Leaf N content was measured in an autoanalyzer (Integral Futura, Alliance Instruments, Frépillon, France). Leaf area duration and net assimilation rate were calculated according to the formulae of Hunt (1978):

$$LAD = \frac{(LAI_2 + LAI_1)(t_2 - t_1)}{2}$$

$$NAR = \frac{[(W_2 - W_1)(\ln LAI_2 - \ln LAI_1)]}{[(LAI_2 - LAI_1)(t_2 - t_1)]}$$

where LAI_1 and LAI_2 are leaf area indices and W_1 and W_2 are biomass at times t_1 and t_2, respectively. At maturity, 8 hills were sampled diagonally from a 5 m^2 harvest area for each plot. Plants were separated into straw and panicles. Straw dry weight was determined after oven drying at 70 °C to constant weight. Panicle number was recorded. Panicles were hand-threshed, and filled spikelets were separated from unfilled spikelets by submerging them in tap water. Three subsamples of 30 g filled spikelets and all unfilled spikelets were taken to count the number of spikelets. Dry weights of rachis and filled and unfilled spikelets were determined after oven drying at 70 °C to constant weight. Spikelets per m^2, grain-filling percentage, grain weight, and HI (filled spikelet weight/total biomass) were calculated. Grain yield was determined from a 5 m^2 area in each plot and adjusted to the standard moisture content of 14%.

Data were analyzed following analysis of variance (Statistix 8.0, Analytical software, Tallahassee, FL, USA) and means of cultivars were compared based on the least significant difference test (LSD) at the 0.05 probability level for each season.

3. RESULTS

GLY2 and YXYZ had the same growth duration of 118 d in early season and 114 d in late season (**Table 1**). GLY2 produced 38% and 17% higher grain yield than YXYZ in early and late season, respectively. Spikelets per m^2 were higher in GLY2 than in YXYZ by 11% in early season and 13% in late season. There was no significant difference in spikelet filling percentage between GLY2 and YXYZ in both early and late seasons. GLY2 had 17% and 6% higher grain weight than YXYZ in early and late season, respectively.

LAI was higher in GLY2 than in YXYZ in both early and late seasons (**Figures 1a** and **1b**), whereas LNC was generally lower in GLY2 than in YXYZ (**Figures 1c** and **1d**). GLY2 had higher LAD but lower NAR than YXYZ in both early and late seasons (**Figures 2a** and **2d**). No significant difference was observed in biomass accumulation between GLY2 and YXYZ in both early and late seasons (**Figures 3a** and **3b**). HI was higher in GLY2 than in YXYZ by 23% in early season and 13% in late season (**Figures 3c** and **3d**).

Table 1. Grain yield and yield components of two rice cultivars grown in early and late seasons in 2013 — *Rendement en grains et composantes du rendement de deux cultivars de riz cultivés sur deux saisons en 2013*.

Cultivar	**Growth duration** (d)	**Grain yield** ($t \cdot ha^{-1}$)	**Spikelets by m²** (× 10^3)	**Spikelet filling** (%)	**Grain weight** (mg)
Early season					
Guiliangyou 2	118	8.28^a	37.0^a	85.8^a	25.6^a
Yuxiangyouzhan	118	6.02^b	33.3^b	82.3^a	21.8^b
Late season					
Guiliangyou 2	114	7.60^a	38.7^a	83.2^a	23.9^a
Yuxiangyouzhan	114	6.47^b	34.2^b	86.6^a	22.6^b

Within a column for each season, means followed by the same letters are not significantly different according to LSD at P = 0.05 — *Dans chaque colonne, pour chaque saison, les moyennes suivies par les mêmes lettres ne sont pas significativement différentes selon LSD,* P = *0,05*.

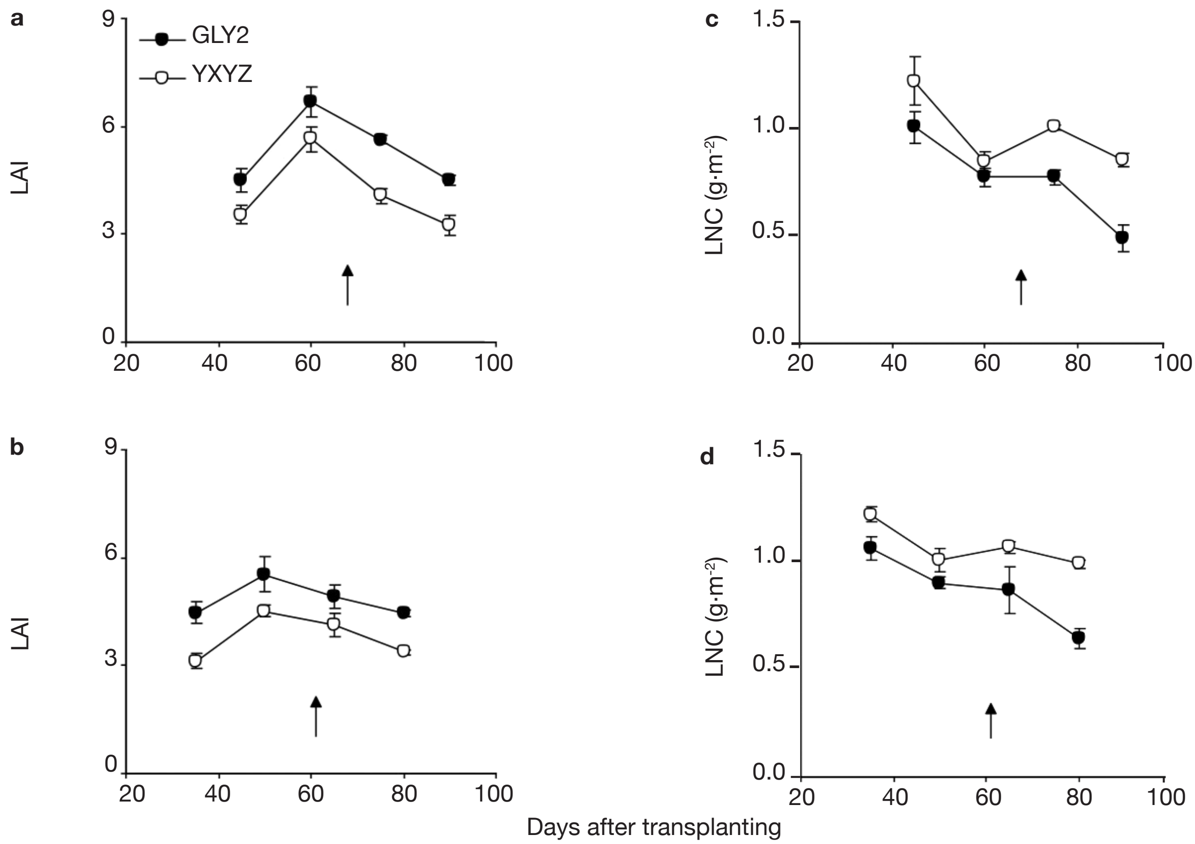

Figure 1. Leaf area index (LAI) and leaf N content (LNC) in rice cultivars Guiliangyou 2 (GLY2) and Yuxiangyouzhan (YXYZ) grown in early (**a**, **c**) and late seasons (**b**, **d**) — *Indice de surface foliaire (LAI) et contenu de la feuille en N (LNC) chez les cultivars de riz Guiliangyou 2 (GLY2) et Yuxiangyouzhan (YXYZ) cultivés en début de saison (**a**, **c**) et en fin de saison (**b**, **d**).*

Arrows denote heading dates — *les flèches indiquent la position des dates*; Vertical lines represent standard errors (*n* = 3) — *les lignes verticales représentent les erreurs standards (*n *= 3).*

4. DISCUSSION

GLY2 outyielded YXYZ with same growth duration in both early and late seasons. Analysis of yield components indicates that more spikelets per m^2 and higher grain weight were responsible for the higher grain yield in GLY2 than in YXYZ. The importance of spikelets per m^2 in enhancing grain yield has been recognized by many researchers (Kropff et al., 1994; Ying et al., 1998; Zhang et al., 2009; Huang et al., 2013). There also have been reports showing that developing rice cultivars with high grain weight is a feasible approach to achieve high grain yield (Jeng et al., 2006; Hongthong et al., 2012).

It is generally considered that short-duration high-yielding rice cultivars should grow rapidly to produce high biomass (Khush, 1995). In general, higher LAI and LAD can lead to a greater crop growth rate (Ying et al., 1998; Ibrahim et al., 2013). In the present study, GLY2 had higher LAI and LAD than YXYZ. However, LNC and NAR were lower in GLY2, which offset its higher LAI and LAD and resulted in a comparable biomass accumulation in the two cultivars. Because there was no significant difference in biomass accumulation between GLY2 and YXYZ, the higher yield in GLY2 was attributed to higher HI than in YXYZ. The HI of modern high-yielding rice cultivars is around 0.5 (Khush, 1995). In this study, the HI of GLY2 reached as high as 0.57 (**Figures 3c** and **3d**). The results of this study are not in agreement with previous studies (Evans et al., 1999; Peng et al., 1999; Laza et al., 2003; Zhang et al., 2009; Huang et al., 2013), which claimed that further improvement in rice yield might be driven from the increased biomass production rather than HI. It is suggested that developing cultivars with high HI through breeding program is a possible approach to increase the short-duration rice yield.

Harvest index is determined by the potential sink size, by the transient photosynthesis during grain formation, and by the remobilization of stored reserves into the growing grain (Blum, 1993). In the present study, GLY2 had higher potential sink size (more

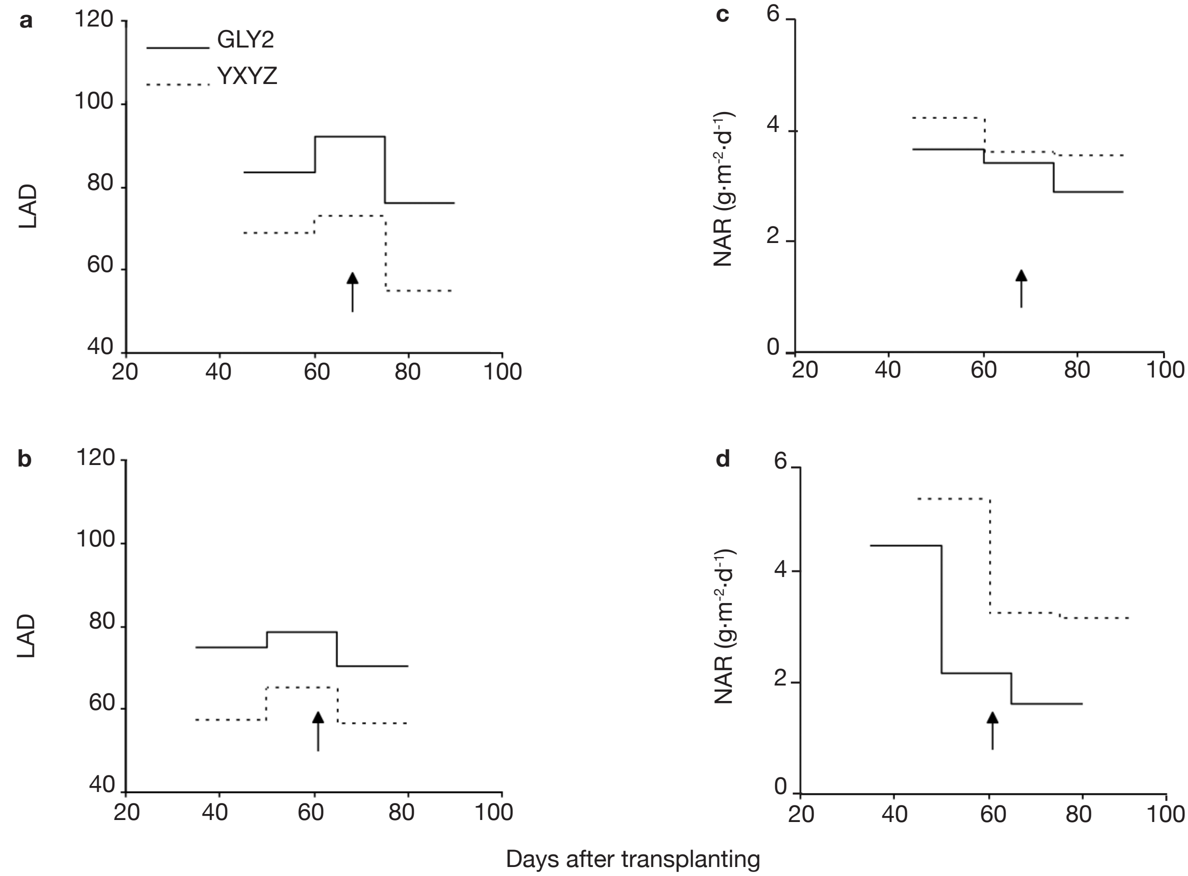

Figure 2. Leaf area duration (LAD) and net assimilation rate (NAR) in rice cultivars Guiliangyou 2 (GLY2) and Yuxiangyouzhan (YXYZ) grown in early (**a**, **c**) and late seasons (**b**, **d**) — *Durée de surface foliaire (LAD) et taux d'assimilation net (NAR) chez les cultivars de riz Guiliangyou 2 (GLY2) et Yuxiangyouzhan (YXYZ) cultivés en début de saison (**a**, **c**) et en fin de saison (**b**, **d**).*

Arrows denote heading dates — *les flèches indiquent la position des dates.*

spikelets per m^2 and higher grain weight) than YXYZ, which was one of the reasons for the higher HI in GLY2. In another approach, no significant difference was observed in biomass accumulation between GLY2 and YXYZ after heading (**Figures 3a** and **3b**), indicating that the difference in HI between the two cultivars was driven by the remobilization of stored reserves into the growing grain but not by the transient photosynthesis during grain formation. Based on the data shown in **figure 3** and the equations described by Yang et al. (2008), we estimated that the remobilization of stored reserves into the growing grain was about 200 g·m^{-2} and 90 g·m^{-2} in GLY2 and YXYZ, respectively. Consistently, LNC decreased more sharply in GLY2 than in YXYZ after heading (**Figures 1c** and **1d**), demonstrating that GLY2 had higher remobilization of N than YXYZ. But on the other hand, the remobilization of N is associated with leaf senescence and thus a decrease in photosynthetic capacity (Dingkuhn et al., 1992). In the present study, similar to LNC, NAR decreased more sharply in GLY2 than in YXYZ after heading (**Figures 1c** and **1d**; **Figures 2c** and **2d**), but biomass accumulation after heading was not reduced in GLY2 compared with YXYZ (**Figures 3a** and **3b**). The possible negative effect of the more sharply decreased LNC and NAR after heading on biomass production in GLY2 might be compensated for by its higher LAI and LAD (**Figures 1a** and **1b**; **Figures 2a** and **2b**). Our results suggest that it is possible to increase HI together with grain yield by improving the potential sink size and the remobilization of stored reserves while maintaining high LAI and LAD in short-duration rice. Although this strategy may incur top heaviness, weak stems and therefore lodging risks, our observations and farmers' assessments revealed that GLY2 shows reasonable lodging resistance. This indicates that further investigations are needed to determine the lodging resistance characteristics of high-yielding rice cultivars with high HI. Moreover, since our study covers only the comparison of two cultivars, further studies involving more cultivars are required to generate more conclusive results.

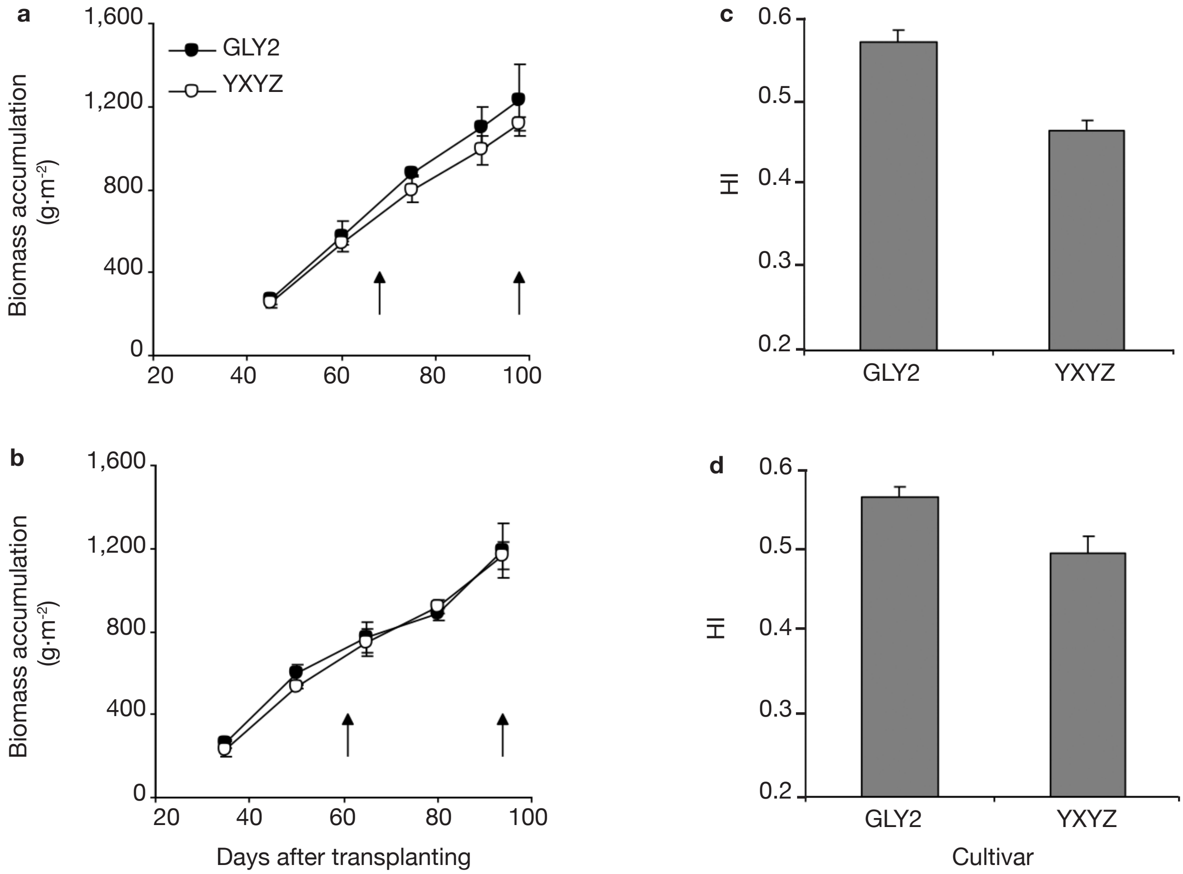

Figure 3. Biomass accumulation and harvest index (HI) in rice cultivars Guiliangyou 2 (GLY2) and Yuxiangyouzhan (YXYZ) grown in early (**a**, **c**) and late seasons (**b**, **d**) — *Accumulation de la biomasse et indice de récolte (HI) dans les cultivars de riz Guiliangyou 2 (GLY2) et Yuxiangyouzhan (YXYZ) cultivés en début de saison (**a**, **c**) et en fin de saison (**b**, **d**).*

Arrows denote heading and maturity dates — *les flèches indiquent la position des dates et les dates de maturité*; Vertical lines represent SE (n = 3) — *les lignes verticales représentent SE (*n *= 3).*

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Bibliography

Akita S., 1989. Improving yield potential in tropical rice. *In*: *Progress in irrigated rice research*. Los Baños, Philippines: International Rice Research Institute, 41-73.

Blum A., 1993. Selection for sustained production in water-deficit environments. *In*: Shibles R. et al., eds. *International crop science, Vol. 1*. Madison, WI, USA: Crop Science Society of America, 343-347.

Cassman K.G., 1999. Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proc. Natl. Acad. Sci. USA*, **96**, 5952-5959.

CRGCST (Cooperative Research Group on Chinese Soil Taxanomy), 2001. *Chinese Soil Taxonomy*. Beijing; New York, USA: Science Press.

Dingkuhn M. et al., 1992. Effect of late-season N fertilization on photosynthesis and yield of transplanted and direct-seeded tropical flooded rice. II. A canopy stratification study. *Field Crops Res.*, **28**, 235-249.

Evans L.T., Visperas R.M. & Vergara B.S., 1984. Morphological and physiological changes among rice varieties used in the Philippines over the last seventy years. *Field Crops Res.*, **8**, 105-125.

Evans L.T. & Fischer R.A., 1999. Yield potential: its definition and significance. *Crop Sci.*, **39**, 1544-1551.

Hongthong P. et al., 2012. Yield formation strategies of a loose-panicle super hybrid rice. *Res. Crops*, **13**, 781-789.

Huang M. et al., 2013. Yield gap analysis of super hybrid rice between two subtropical environments. *Aust. J. Crop Sci.*, **7**, 600-608.

Hunt R., 1978. *Plant growth analysis*. London: Edward Arnold.

Ibrahim Md. et al., 2013. Comparisons of yield and growth behaviors of hybrid rice under different nitrogen management methods in tropical and subtropical environments. *J. Integr. Agric*., **12**, 621-629.

Jeng T.L. et al., 2006. Yield and grain uniformity in contrasting rice genotypes suitable for different growth environments. *Field Crops Res*., **99**, 59-66.

Jeon J. et al., 2011. Genetic and molecular insights into enhancement of rice yield potential. *J. Plant Biol*., **54**, 1-9.

Khush G.S., 1995. Modern varieties–Their real contribution to food supply and equity. *GeoJournal*, **35**, 275-284.

Khush G.S., 2001. Green revolution: the way forward. *Nat. Rev. Genet*., **2**, 815-822.

Kropff M.J., Cassman K.G., Van Laar H.H. & Peng S., 1993. Nitrogen and yield potential of irrigated rice. *Plant Soil*, **156**, 392-394.

Kropff M.J. et al., 1994. Quantitative understanding of yield potential. *In*: Cassman K.G., ed. *Breaking the yield barrier.* Los Baños, Philippines: International Rice Research Institute, 21-38.

Laza R.C., Peng S., Akita S. & Saka H., 2003. Contribution of biomass partitioning and translocation of grain yield under sub-optimum growing conditions in irrigated rice. *Plant Prod. Sci*., **6**, 28-35.

Peng S. et al., 1999. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. *Crop Sci*., **39**, 1552-1559.

San-oh Y., Mano Y., Ookawa T. & Hirasawa T., 2004. Comparison of dry matter production and associated characteristics between direct-sown and transplanted rice plants in a submerged paddy field and relationships to planting patterns. *Field Crops Res*., **87**, 43-58.

Umashankar R., Babu C., Kumar P.S. & Prakash R., 2005. Integrated nutrient management practices on growth and yield of direct seeded low land rice. *Asian J. Plant Sci*., **4**, 23-26.

Yang W. et al., 2008. Yield gap analysis between dry and wet season rice crop grown under high-yielding management conditions. *Agron. J*., **100**, 1390-1395.

Ying J. et al., 1998. Comparison of high-yield rice in tropical and subtropical environments. I. Determinants of grain and dry matter yields. *Field Crops Res*., **57**, 71-84.

Zhang Q., 2007. Strategies for developing green super rice. *Proc. Natl. Acad. Sci. USA*, **104**, 16402–16409.

Zhang Y. et al., 2009. Yield potential and radiation use efficiency of "super" hybrid rice grown under subtropical conditions. *Field Crops Res*., **114**, 91-98.

(25 ref.)