Research Assessment Exercise 2020
Impact Case Study

University: Hong Kong Baptist University
Unit of Assessment: 01 Biological Sciences

Title of case study: Controlled soil drying enhances yield and saves water in rice production

1. Summary of the impact

Prof. Jianhua Zhang's group has focused on the development of a unique irrigation method for rice. The core effect of this method is the better utilisation of pre-stored carbon reserves in the rice stem for grain filling. Application of the 'Zhang method' leads to about a 10% increase in grain yield and a 30% reduction in water use. The most reliably quantified impact is from Jiangsu Province, China, where adoption of this method has led to an increased income of over **RMB 4 billion for the participating farmers**. Longer-term impacts include increased yields, water savings and changed rice cultivation technique.

2. Underpinning research

Prof. Zhang's research focuses on plant water stress, but his passion for rice research was ignited in the 1970s when he was farming in a collective farm in Jiangsu Province. In one year, his family's small rice plot had virtually no irrigation after flowering but produced a better yield than usual with almost bursting (over-filled) grains. He bore that surprising observation in mind and investigated the phenomenon only after he encountered grain filling problems in water-saving crop production as a researcher in the 1990s, a story covered in an article by Nature [*10*].

In the 1990s, Prof. Zhang was leading a team at HKBU collaborating with Prof. Baolin Su at the China Agriculture University on water-saving wheat production in the North China Plain, where over-exploitation of underground water is a major concern. They successfully reduced the number of irrigation events from a conventional four times per season to one time. As a result, the crop water use efficiency was greatly improved. However, the yield was significantly reduced, mainly due to the reduced grain kernel weight [*11*]. Lack of one irrigation after flowering led to early plant senescence and shortened the grain filling period, which led to a much smaller kernel size.

In analysing this failure in wheat to maximise the grain filling period under insufficient irrigation, Prof. Zhang quickly recalled his experiences as a farmer in the 1970s and realised that the adverse effect of reduced irrigation on wheat grain filling might be different to that of rice. Rice needs to initiate whole plant senescence so that their pre-stored carbon reserve in the stem can be remobilised for grain filling. Contribution of this remobilised carbon to the final grain weight varies between 20% and 40% in rice, a problem long known but underappreciated. Could this carbohydrate remobilisation be maximised by controlled irrigation and accelerated whole plant senescence? Funded by two continuous grants from the RGC [*7, 8*], Prof. Zhang decided to test this idea by manipulating whole plant senescence through controlled deficit irrigation. This work was done in collaboration with Prof. Jianchang Yang at Yangzhou University, where field experiments (not feasible in Hong Kong) were conducted. They found that in cases where whole plant senescence is unfavourably delayed (e.g. under high levels of fertilisers), reduced irrigation greatly promoted whole plant senescence and enhanced carbon remobilisation into the grains. The concurrent photosynthesis is reduced due to the shortened grain

filling period, but the benefit of increased utilisation of pre-stored reserves easily outweighs the loss caused by the reduced duration of photosynthesis [*1, 2*].

Subsequent physiological studies showed that plant hormones abscisic acid and ethylene are the key regulators in transmitting the soil drying signal and the initiation of whole plant senescence [*3*]. Activity of key enzymes involved in sucrose-to-starch conversion in the grains are also enhanced [*4, 5*]. The work was highly cited and summarised as a prestigious Tansley Review in *New Phytologist* [*6*]. In 2012, Prof. Zhang obtained a major grant from the Ministry of Science and Technology in China to continue this research into the use of water-saving irrigations on other crops [*9*].

3. References to the research

3a. Six papers selected of 55 publications for this research topic (Zhang J* for corresponding)

1. Yang J, **Zhang J***, Wang Z, Zhu Q, Wang W. 2001. Remobilization of carbon reserves in response to water-deficit during grain filling of rice. *Field Crops Research* 71, 47-55. doi.org/10.1016/S0378-4290(01)00147-2.
2. Yang J, **Zhang J***, Liu L, Wang Z, Zhu Q. 2002. Carbon remobilization and grain filling in japonica/indica hybrid rice subjected to post-anthesis water deficits. *Agronomy Journal* 94, 102-109. doi:10.2134/agronj2002.1020.
3. Yang J, **Zhang J***, Wang Z, Zhu Q, Wang W. 2001. Hormonal changes in the grains of rice subjected to water stress during grain filling. *Plant Physiology* 127, 315-323. doi.org/10.1104/pp.127.1.315.
4. Yang J, **Zhang J***, Wang Z, Zhu Q. 2001. Activities of starch hydrolytic enzymes and sucrose-phosphate synthase in the stems of rice subjected to water stress during grain filling. *Journal of Experimental Botany* 52, 2169-2179. doi.org/10.1093/jexbot/52.364.2169.
5. Yang J, **Zhang J***, Wang Z, Xu G, Zhu Q. 2004. Activities of key enzymes in sucrose to starch conversion in wheat grains subjected to water deficit during grain filling. *Plant Physiology* 135, 1621-1629. doi.org/10.1104/pp.104.041038.
6. Yang J, **Zhang J***. 2006. Grain filling of cereals under soil drying. *New Phytologist* 169, 223-236. (Tansley Review). 10.1111/j.1469-8137.2005.01597.x.

3b. Three research grants in supporting this research (Zhang J as PI)

7. Hong Kong **Research Grants Council**, Competitive Earmarked Research Grant, "Soil drying in relation to the remobilisation of carbon reserve during grain-filling period of rice and wheat" **HK$855,500**. Project period: Nov 2000-Oct 2003. (RGC reference: HKBU 2052/00M)
8. Hong Kong **Research Grants Council**, Competitive Earmarked Research Grant, "Soil drying at the grain-filling stage of rice and wheat: physiology and its application in crop production" **HK$ 748,800**. Project period: Jan 2005-Dec 2006. (RGC reference: HKBU 2149/04M)
9. Ministry of Science and Technology in China (MoST), the National Basic Research Program (the 973 Programme), "Mechanism and regulation in enhancing crop water use efficiency", as Co-PI and leader for a subgroup of "Whole plant response and regulation to water stress". **RMB 40 million**. Project period: 1 Jan 2012-31 Dec 2016. (MoST reference: 2012CB114300).

4. Details of the impact

Afflicted by numerous food shortages in the past, food security has become one of the highest priorities in China and many other parts of the world. Irrigation for farming depletes China's limited water supply, which is only about one-fourth of the world's per capita. Extensive implementation of Prof. Zhang's irrigation method has generated sizeable impacts economically, socially and environmentally.

4a: Increase of rice yield and farmers' income

Research by Prof. Zhang and his collaborators on rice grain filling has led to the development of the Alternate Wetting and Drying (**AWD**) irrigation technique for practical use during the entire rice growing season [*12*]. In contrast to other water-saving and/or high yield rice cultivation techniques developed elsewhere, such as Aerobic Rice cultivation from the International Rice Research Institute (IRRI) or System of Rice Intensification (SRI) from Prof. Norman Uphoff at Cornell University, Prof. Zhang's group revealed the science behind the promotion of grain filling and carbon remobilisation and emphasised the importance of controlled soil drying after flowering. They worked out many straightforward steps that can be easily implemented by farmers to control the "appropriate level of soil drying", such as soil colour changes (dark to light), cracks (size) and hardness of soil (whether footprints are visible or not). In addition, a simple device using a PVC tube with many side holes inserted in the paddy field has been developed to indicate how dry the soil is from observation of marks on the walls inside the tube. All of these details are summarised in a patent granted recently [*13*].

After resolving technical issues, the team needed a platform to help extend the technology to the farmers. China has a well-structured agriculture extension network at different government levels: province, city, county and town. With the support and coordination of the Agriculture Extension Head Station of Jiangsu Province (http://www.jsnongji.com), Profs Zhang and Yang have set up several demonstration fields in Jiangsu Province to train technicians at Agriculture Extension Stations at city and county levels. Equipped with these techniques, these farming technicians transferred details of new irrigation practices to township technicians and finally to the millions of individual farmers. The extension network has been very successful. For example, the Jiangsu Agriculture Extension Head Station estimated that in 2016, about 1.25 million hectares of rice fields in Jiangsu had adopted AWD free of charge for rice production, accounting for 55% of the total rice acreage in Jiangsu. A huge economic return has been generated as a result of AWD adoption. For example, during the five years from 2012 to 2016, 3.73 million hectares of rice fields were managed with AWD and an estimated increase of **RMB 4.6 billion** in farmers' income has been generated due to increased rice yield and reduced irrigation costs in Jiangsu Province alone [*14*].

Additional testimonials have come from Agriculture Extension Stations at the city level. For example, in Yangzhou City, AWD was adopted for 344,533 hectares of rice fields from 2013 to 2017. An increased economic return of RMB 427 million was estimated. Similarly, in Lianyungang City AWD was adopted for 426,600 hectares of rice fields during 2013-2017 and a total economic gain of over RMB 553 million was estimated [*14*]. The Education Bureau of Jiangsu Province even organised a special meeting to certify AWD in rice production and awarded an *ad hoc* certificate for this achievement [*15*]. With such certification, details of the new technique are circulated to all the Agriculture Extension Stations at different administrative levels so that they can promote it in the whole province. Nation-wide promotion of AWD has been initiated and an even bigger impact is expected in the coming years. Internationally, AWD has been successfully promoted in Bangladesh, Nepal and Ghana for examples [*16*].

4b: Change of concepts and practices in rice water management

Traditional concepts and practices in rice water management emphasise that rice is sensitive to water stress and a steady water level should be kept in the paddy field for virtually all of the production time. Especially at grain filling time, the water level is kept high so that the grain filling period may be maintained for as long as possible. These recommendations are written in all textbooks on rice cultivation. Prof. Zhang's group has demonstrated to farmers that the traditional thinking and practices

should be changed. High yielding rice crops can be achieved with much less watering, and the benefits are more than just irrigation reduction and rice yield increase. For example, a dry field becomes more accessible to harvesting machines, allowing an earlier harvest of rice. A less humid canopy also alleviates problems with both rice diseases such as rice blight and rice blast, and with pests including rice plant hoppers [*14*].

4c: Recognition of contribution to water-saving agriculture

Prof. Zhang is well-recognised as a pioneer in water-saving agriculture internationally. In recognition of his work on deficit irrigation and rice grain filling, he was profiled by *Nature* as one of the '**Five Crop Researchers Who Could Change the World**' in 2008 [*10*]. In collaboration with Prof. Yang at Yangzhou University, their research and contributions to water-saving agriculture have led to multiple prestigious national awards, including a Natural Science Award (First Prize) from the Ministry of Education of China for "*Method and mechanism to enhance carbon remobilisation and grain filling in rice and wheat*" in 2015, and a State Natural Science Award (Second Prize) from the State Council of China for "*Regulation and physiological mechanism in enhancing the remobilisation of assimilates to grain and grain-filling in rice and wheat*" in 2017 [*17*]. These awards clearly demonstrate that the impact of Prof. Zhang's research has extended far beyond academia. The awards and their impact on agriculture were also intensively covered in several local and national newspapers in China [18,19].

5. Sources to corroborate the impact

Also see 9 references in Section 3 above, plus (uploaded as file 1-10):

10(1) News Feature: **Five Crop Researchers Who Could Change the World**. *Nature* 456, 563-568, 4 December 2008. doi:10.1038/456563a

11(2) **Zhang J**, Sui X, Li B, Su B, Li J, Zhou D. 1998. An improved water-use efficiency for winter wheat grown under reduced irrigation. *Field Crops Research* 59, 91-98.

12(3) Zhang H, Xue Y, Z Wang, Yang J, Zhang J. 2009. An alternate wetting and moderate soil drying regime improves root and shoot growth in rice. *Crop Science* 49, 2246-2260.

13(4) Patent Name: A water-saving irrigation method for rice production. China Patent Office. Registration no: ZL 2015 1 020564.3. Date of approval: 08 March 2017. Inventors: Yang Jianchang, Xu Gengwen, **Zhang Jianhua**, Wang Zhiqing.

14(5) Three Certificates of Extension of Jiangsu Province, Yangzhou City and Lianyungang City. 2017

15(6) Education Bureau of Jiangsu Province. 2010. *Certificate of Science and Technology Achievement*: Development of rice cultivation technology for high yield and high efficient uses of water and nutrients.

16(7) Letter from Prof Ian Dodd at Lancaster University about his promotion of AWD in Bangladesh, Nepal and Ghana.

17(8) Two Prizes from the Ministry of Education of China and the State Council of China in 2015 and 2018 respectively

18(9) Two News reports on the award of National Natural Science Second Prize of China to the Yangzhou University by the State Council of China in January 2018. http://news.yzu.edu.cn/art/2018/1/8/art_40581_581884.html http://js.people.com.cn/n2/2018/0109/c360301-31123149.html

19(10) Editing Division of China Science and Technology Achievements. Technique and physiological mechanisms in promoting rice and wheat grain filling through better remobilization of assimilates to grains. *China Science and Technology Achievements*.2018;9:75,78. (http://caod.oriprobe.com/articles/54441289/cu_jin_dao_mai_tong_hua_wu_xiang_zi_li_zhuan_yun_h.htm)