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Can potato add to China's food self-sufficiency? The scope for increasing potato production in China

N. Wang[a,*], P. Reidsma[a], A.A. Pronk[b], A.J.W. de Wit[c], M.K. van Ittersum[a]

[a] Department of Plant Sciences, Group Plant Production Systems, Wageningen Univeristy & Research, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[b] Wageningen University & Research, Agrosystems Research, P.O. Box 16, 6700 AA Wageningen, The Netherlands
[c] Wageningen University & Research, P.O. Box 47, 6700AA Wageningen, The Netherlands

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ABSTRACT

China is enhancing potato production in both area and quantity. While the potato area is large, the actual yields remain low. Besides, the water resources used for irrigation are increasingly under pressure in potato production areas. This study aimed to assess the scope for increasing potato production in China. The key climate zones in China were identified, for which the potential yield (Yp) and water limited yield (Yw) of potato (expressed in fresh matter (FM)) were estimated by two crop growth models over 10 years (2006–2015). The Yp and Yw and yield gaps (i.e., the difference between Yp and actual yield (Ya) under irrigated conditions (Yg-p) and between Yw and Ya under rainfed conditions (Yg-w)) were evaluated at local, provincial and national level, for potatoes under both irrigated and rainfed conditions. The water availability through rainfall, water productivity (WP) and the water input gaps to realize potential rather than water-limited potato yields were identified at provincial level. The Yp in the country was on average 50.1 ton FM ha^{-1}, and Yg-p as a percentage of Yp was 66%. At provincial level, the Yp varied from 38.8 ton FM ha^{-1} in Sichuan in the southwest to 66.4 ton FM ha^{-1} in Qinghai in the north. At national level, the Yw was 43.7 ton FM ha^{-1} and Yg-w as a percentage of Yw was 61%. At provincial level, the Yw was lowest in Shaanxi (27.7 ton FM ha^{-1}) and highest in Qinghai (57.9 ton FM ha^{-1}). Water productivity for potential yield (WP-p) ranged between 30.7 and 54 kg dry matter (DM) mm^{-1} ha^{-1} in Shaanxi and Qinghai, respectively, and for actual yield (WP-a) between 7.9 kg DM mm^{-1} ha^{-1} (Shanxi) and 22.3 kg DM mm^{-1} ha^{-1} (Sichuan). Water supply through rainfall is close to sufficient for non-water limiting potato growth in the southwest. The water input gap in the north was highest in Shaanxi (i.e., 243 mm) and lowest in Heilongjiang (i.e., 39 mm). There is a large scope to improve potato yields at current rainfall levels, especially in Qinghai and Heilongjiang in the north and in Guizhou in the southwest. By closing the exploitable yield gap (i.e., difference between 80% of Yp - or of Yw - and Ya) for the current production area, potato could contribute to an additional 1.1 and 0.9 10^{14} kcal, respectively, under irrigated and rainfed conditions. This is much more than that for rice (0.2 10^{14} kcal extra energy due to yield gap closure) under irrigated conditions, and similar or more than for maize under irrigated (1.0 10^{14} kcal) and rainfed (0.5 10^{14} kcal) conditions. We conclude that compared with the cereal staple crops, potato has a larger potential to maintain domestic food security and self-sufficiency, and to enhance water use efficiency.

1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important crop in the world in terms of global production quantity in fresh matter (FAO, 2016a, 2016b). The crop is increasingly important for maintaining food security and stability, particularly in intensive agricultural regions in developing countries (He et al., 2012; Hijmans and Spooner, 2001; DeFauw et al., 2012). Being the number one country in terms of potato production area (i.e., 30% of world production area) and production (i.e., 24% of world production), China has taken a dominant position in the global potato industry (FAO, 2016b, Jansky et al., 2009; Wang and Zhang, 2004). Yet, the continuous increase in population density and pressure on land in China drives a further intensification of potato production.

Potatoes are mainly grown in four agro-ecological zones in China: in the north (49% of total area), southwest (39%), south (7%) and Central

* Corresponding author.
E-mail addresses: na.wang@wur.nl (N. Wang), pytrik.reidsma@wur.nl (P. Reidsma), annette.pronk@wur.nl (A.A. Pronk), allard.dewit@wur.nl (A.J.W. de Wit), martin.vanittersum@wur.nl (M.K. van Ittersum).

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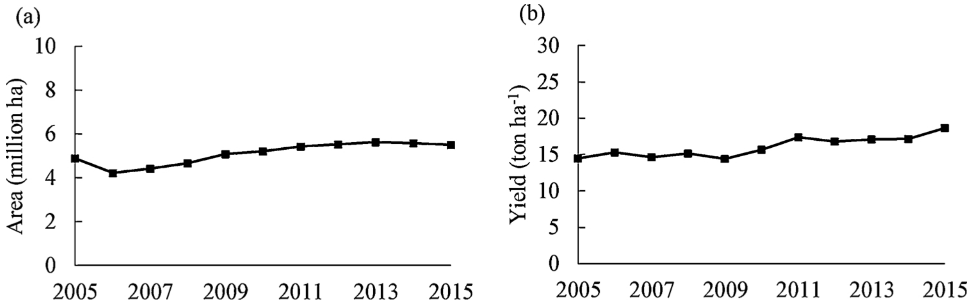

Fig. 1. Annual production area (a) and fresh matter yield (b) of potato in China from 2005 to 2015.

Plains (5%) (MOA,2008). There are various production systems across the country: summer cultivation in the north; two cultivations in the central plains; winter cultivation in the south and both summer and winter production systems in the southwest. Table potato is widely cultivated across the country. Coarse starch is traditionally the dominant processed product, while the area under varieties processed to flakes, French fries and crisps is quickly expanding, which is facilitated by the rapid growth of the country's economy and rising demand for diversified diets.

The fresh matter yield (FM) of potatoes (18.7 ton FM ha^{-1} in 2015, Fig. 1) is low compared to other dominant potato production countries such as the United States (47.1 ton FM ha^{-1}), the Netherlands (45.7 ton FM ha^{-1}), Poland (27.7 ton FM ha^{-1}), and India (22.9 ton FM ha^{-1}) (NBSC, 2016; FAO, 2016a). This is remarkable given the strong increase in yields and the relatively small yield gaps of cereal crops in China (Cassman et al., 2003; Lobell et al., 2009; Lu and Fan, 2013; Meng et al., 2013; Qu et al., 2005; Van Ittersum and Rabbinge, 1997; Van Ittersum et al., 2013; Van Wart et al., 2013; Zhang et al., 2014), which are estimated to be ca. 33% for rainfed maize, 27% and 44%, respectively, for irrigated and rainfed rice (GYGA, 2017a), and 11% for irrigated wheat (Liu et al., 2011).

Agricultural production is estimated to use as much as 73% of total fresh water resources in China (Qu et al., 2005). Water resources to maintain the continuously increasing agricultural production are under severe pressure in many arable lands of the country. In arid and semi-arid regions of China (i.e., north and northwest), potatoes are mainly produced under rainfed conditions, and irrigation is sometimes applied, mainly on large-scale farms (personal communication with the local potato processing companies). With the extension of potato processing industry in China, it is likely that irrigation will become more profitable in the current rainfed areas to satisfy the demand. Thus a critical question is how much water is needed to increase yields from water limited to potential (water input gap).

The production capacity of a crop in a given area can be derived by evaluating the potential yield (Yp) under irrigated conditions or the water limited yield (Yw) under rainfed conditions, and calculating the so-called yield gap (i.e., Yg-p refers to the difference between Yp and the actual yield (Ya), and Yg-w to the difference between Yw and Ya) (Van Ittersum and Rabbinge, 1997; Van Ittersum et al., 2013). Crop growth models have been argued to be the most robust tool for simulating potential yield under diverse climatic conditions (Van Ittersum et al., 2013). So far, there is however little literature on estimating potential yield of potatoes in China.

To safeguard domestic food supply, China is enhancing potato production as the fourth most important staple crop after rice, wheat and maize (MOA, 2016). The expansion of potato production is likely to be economically and environmentally viable in regions with high biophysical possibilities and low irrigation requirements. In this study, crop models (i.e., WOFOST, LINTUL POTATO DSS) were used to estimate potential and water limited yield of potato in China as well as yield gaps and water input gaps. We compare the slack in production of potato on the present potato area with the slack in cereal production on the existing cereal area to assess possible contributions to food self-sufficiency in China.

2. Methods

We followed the protocol developed for the Global Yield Gap Atlas (Global Yield Gap Atlas (GYGA), www.yieldgap.org) (Van Ittersum et al., 2013; Grassini et al., 2015; Van Bussel et al., 2015) to estimate potato yield gaps. The important climate zones for potato in China and so-called reference weather stations (RWSs) within these climate zones were identified following the procedure described by Van Bussel et al. (2015). The two crop growth models WOFOST and LINTUL POTATO DSS were applied to estimate potential dry matter (DM) yield, which was then converted to fresh matter (FM) (Yp). The water limited DM yield was only estimated by WOFOST and converted to FM (Yw). Two crop growth models were used, because model comparisons have shown that simulated yields may vary between models (Asseng et al., 2013; Fleisher et al., 2017). For potato, two or three models are recommended, depending on the site-specific conditions (Fleisher et al., 2017). Comparing simulations of different models improves understanding of yield potentials due to inherent uncertainty of model simulations. The Yp, Yw, Yg-p and Yg-w were estimated using the weather data from the RWSs, and scaled up to climate zones, provincial and national level. The results will also be published on www.yieldgap.org. Water input gaps for irrigated potatoes were assessed at provincial level, based on the extra water needed to obtain Yp, rather than Yw, assuming that irrigation would be viable in the current dryland systems in the future. Finally, the additional food (expressed in kcal) that can be obtained by closing the exploitable yield gap (Van Ittersum et al., 2013), i.e. the gap between 80% of Yp and Ya (under irrigated conditions) or between 80% of Yw and Ya (under rainfed conditions), was assessed and compared with the amount (in kcal) that can be added through exploitable yield gap closure (to 80% of Yw or Yp) of rice, maize and wheat. In this way we estimated the possible contribution of the potato crop to future food security and self-sufficiency of China.

2.1. Important climate zones and reference weather stations

The locations and area of potato production in China (i.e., both irrigated and rainfed) were retrieved from SPAM2005 (You et al., 2014) and were compiled and schematically interpreted using ArcGIS (Fig. 2). Information on the potato area under irrigation according to SPAM2005 was not used, as it was deemed not accurate enough due to the fact that many potato processing companies (which mainly apply irrigation systems) have been established recently in China (personal communication with the companies) and this was not included in the SPAM2005 database yet. Yield gaps were benchmarked against both Yp and Yw for the entire country due to the lack of good spatial data for irrigated potato areas.

In the country, a total of 136 climate zones were identified based on the climate zonation procedure in GYGA (Van Wart et al., 2013). Designated Climate Zones (DCZs) were selected as zones covering more