Apple Yield and K Use

Subjects: Agronomy
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In order to meet the growing food demand of the global population and maintain sustainable soil fertility, there is an urgent need to optimize fertilizer application amount in agricultural production practices. Most of the existing studies on the optimal K rates for apple orchards were based on case studies and lack information on optimizing K-fertilizer management on a regional scale. Here, we used the method of combining meta-analysis with the K application rate-yield relationship model to quantify and summarize the optimal K rates of the Loess Plateau and Bohai Bay regions in China. We built a dataset based on 159 observations obtained from 18 peer-reviewed literature studies distributed in 15 different research sites and evaluated the regional-scale optimal K rates for apple production. The results showed that the linear plus platform model was more suitable for estimating the regional-scale optimal K rates, which were 208.33 and 176.61 kg K ha^{-1} for the Loess Plateau and Bohai Bay regions of China, respectively. Compared with high K application rates, the optimal K rates increased K use efficiency by 45.88–68.57%, with almost no yield losses. The optimal K rates also enhanced the yield by 6.30% compared with the low K application rates.

Keywords: optimal K rates ; K use efficiency ; yield ; apple orchards

1. Introduction

Apple is the fourth most important fruit crop in the world after all citrus, grapes, and bananas and widely distributed around the world, especially in China, due to its strong adaptability to the growing environment [1]. Delicious and nutritious apples are a kind of fruit that everyone eats widely in daily life [2][3]. The per capita consumption of apples in the world increased sharply from 2.1 kg in 2008 to 9.2 kg in 2013 [4][5]. The global population is expected to reach 9 billion by the mid-21st century [6]. Responding to the future apple demand originated from the rapid population growth will require increasing apple yields without expanding orchard areas and increasing environmental risks while maintaining soil fertility. China is the largest apple producer in the world [7][8][9][10]. As of 2013, the annual fresh apples yields were about 39.7 million tons, and the planting area was 2.41 million hectares, accounting for 49 and 46% of the world's apple yields and planting area, respectively [5]. Apple growth requires not only suitable soil and climatic conditions [11][12] but also a reasonable fertilization strategy necessary for maintaining a sustainable apple production [13][14]. Irrational fertilization, especially insufficient fertilization, will inevitably cause yield loss [15]. Potassium (K) is an essential nutrient element in the physiological growth process of apples [16][17][18], increasing the yield and quality of apples [19][20] by participating in important biochemical processes such as photosynthesis [15][21][22][23], various enzyme activation [24][25][26][27], protein synthesis [15], sugar transport [28] and stomatal activity [29]. However, many farmers in poverty-stricken areas, especially in Africa, did not apply K due to the sky-high cost of K-fertilizer [30], resulting in K deficiency in large areas of farmland [31][32], making K a key limiting factor in agro-production in the region [33]. In view of the irreplaceability of K-fertilizer in apple production, rational K-fertilizer management is an important agronomic practice to increase apple yield and maintain soil K fertility.

However, the rational K application rate for apple production varies greatly among the research results of different regions. So much, in fact, that the optimal K rate at the regional scale required for raising yield is not easy to forecast, and K-fertilizer is usually applied in production practices higher than the amount needed by crops. Excessive K-fertilizer application reduces the absorption of cations such as calcium, magnesium by crops [29], destroys the nutritional structure and balance in the soil, aggravates the deterioration of soil fertility [34], weakens crop productivity, and causes apple 'bitter pit disease' [35][36][37]. These negative impacts are very detrimental to the sustainable development of agricultural systems. K use efficiency (KUE) is usually used to evaluate excessive K application [38], defined as the ratio of yield to corresponding K application. Globally, high KUE is needed to improve the sustainable development of an agricultural system. However, the estimated global KUE for cereal production is only 19% [39], indicating that excessive K application may lead to significant loss of K (e.g., leaching or erosion) and serious problems with low KUE [40]. Li et al.'s [41] research on Red Fuji apple in Shaanxi showed that on the basis of applying nitrogen and phosphorus fertilizer, the yield increased at a decreasing rate with an increase in K application rate, and the amount of K-fertilizer had appropriate limits. Furthermore, Jin et al. [42] found that the yield of Red Fuji apple improved with an increase in K application rate below a certain value and exceeded this value, resulting in a decrease in yield. Therefore, a reasonable K application rate is an effective method to maintain crop yield and improve KUE.

We have been facing the serious unscientific application of K-fertilizer in most regions for a long time and the social, economic, ecological, and environmental problems caused by it, determining that the appropriate K application rate has become one of the hot topics in agriculture in the world today [43][44][45]. Although there were many studies on the effect of K-fertilizer on apple yield based on field experiments, these results were applicable to specific sites rather than large-scale agro-ecological regions.

Apple is an important economic fruit crop in China. Considering the biological characteristics, meteorological conditions, and geographic locations, China was divided into four different apple cultivation regions: Loess Plateau, Bohai Bay, the old channel of the Yellow River, and the Southwest Cold Highland (**Figure 1**). In the four apple cultivation regions, the Loess Plateau and Bohai Bay are the two major apple-producing regions in China [46], and they are recognized by the United Nations Food and Agriculture Organization as the world's best eugenic regions for apples, maintaining their green and sustainable development in the soil-environment system. It is an important foundation for meeting people's living quality needs and maintaining the international competitiveness of China's apple industry. Based on this, this study focuses on these two regions.

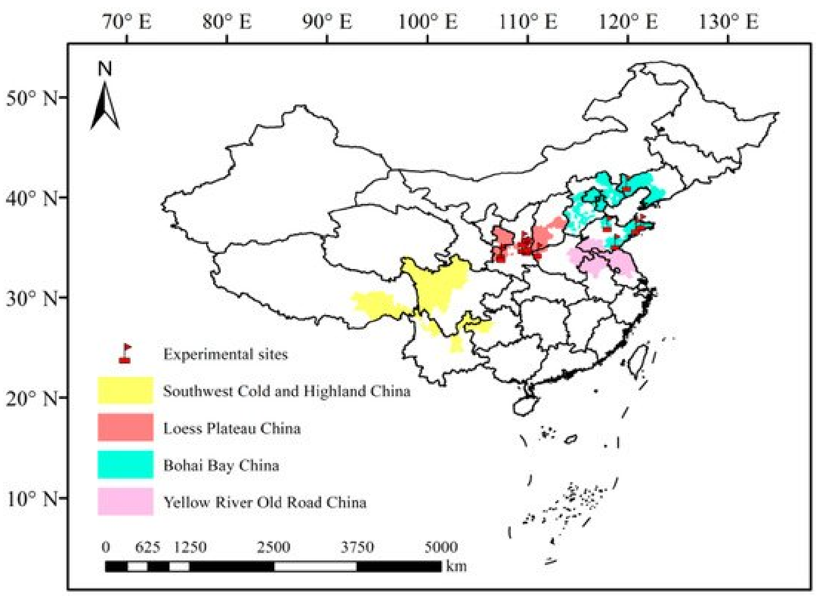


Figure 1. Geo-location of the four major apple cultivation areas in China and the specific apple orchard test sites in the literature compiled by meta-analysis.

To the best of our knowledge, the method of combining meta-analysis with a yield-fertilizer relational model had not been attempted to evaluate and quantify the regional-scale optimal K rate based on the sustainability of apple yield in the two major apple-producing regions of the Loess Plateau and Bohai Bay in China recently. A meta-analysis helps to identify specific data patterns only when data from a wide range of agronomic conditions and production systems are combined and analyzed in environmental and agronomic contexts [47]. In the present study, by means of meta-analysis we aim to integrate the published literature and establish the data sets of apple yield, K application rate, and KUE in the Loess Plateau and Bohai Bay of China and reveal the regional-scale optimal K rate for maintaining apple yield and improving KUE. We intended to settle the following confusions: (1) What are the regional-scale optimal K rates in apple cultivation areas in the Loess Plateau and Bohai Bay in China? (2) What is the relationship between indigenous K supply (IKS) and K application? (3) How will apple yield and KUE change if the regional-scale optimal K rate is applied?

2. Indigenous K supply (IKS) in Different Production Regions

It is essential to analyze the indigenous K supply (IKS) in order to estimate the optimal K rate for apple orchards in different regions. So, we counted the distribution of IKS in the Loess Plateau and Bohai Bay of China (**Figure 3**). The average IKS for these two regions was 28.33 t ha^{-1}, ranging from 14.57 to 39.47 t ha^{-1}, of which 63.95% were concentrated between 22–34 t h^{-1} (**Figure 3**a). Generally speaking, less K-fertilizer was applied in areas with a higher IKS under certain target yields [48]. The mean IKS for the Bohai Bay area was 34.55 t ha^{-1}, which was 37.24% higher than that for the Loess Plateau (**Figure 3**b), the fewest optimal K application (176.61 kg K ha^{-1}), and the maximum predicted yield (39.89 t ha^{-1}) were estimated for the corresponding area (Namely Bohai Bay) (**Figure 2**), indicating that IKS played a key role in the rational formulation of K management policies and final yield. Simultaneously, this also seems to confirm that the amount of K-fertilizer required for harvest response yield does decrease as IKS increase. Jing et al. [49] also reached similar conclusions on the role of INS (abbreviation for indigenous N supply) in two paddy rice species.

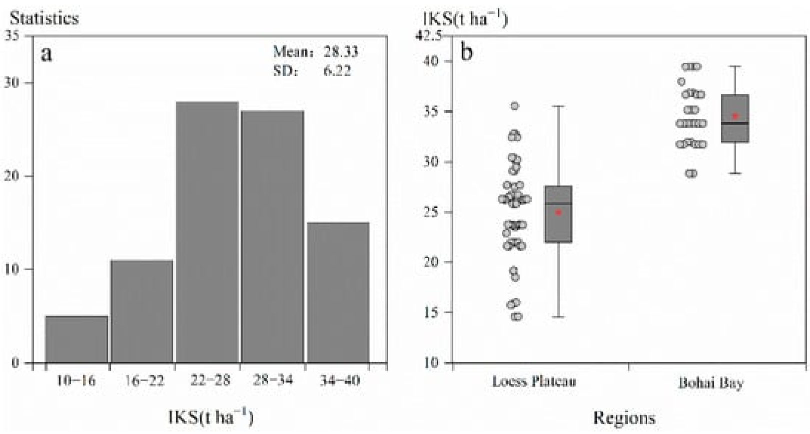
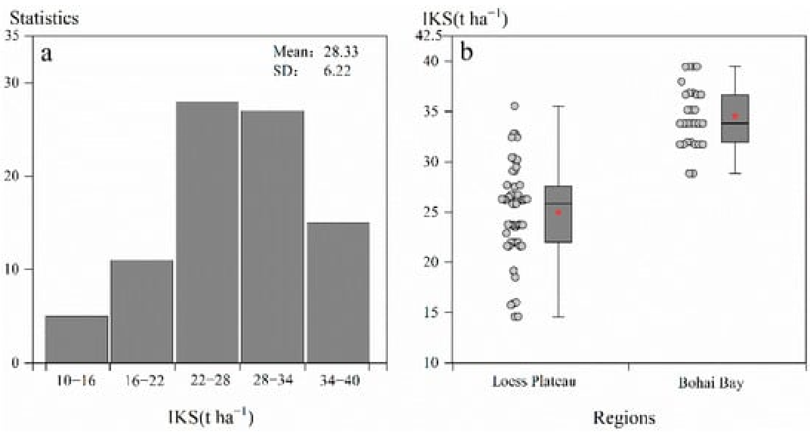


Figure 3. Statistics of soil indigenous K supply (IKS) from apple production areas in Loess Plateau and Bohai Bay of China (**a**) and comparison of IKS between these two areas (**b**). Mean, average IKS of the entire study area; SD, standard deviation. ★ represents the average IKS at regional scale.



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Apple trees have the instinct to store nutrients in advance. They are pre-absorbed and stored by a roots' sensitive response to changes in soil K and their own needs to prevent potential demand when K supply is deficient. In the soil with abundant IKS, apple trees can absorb and store more K in advance, so the application of less K fertilizer can maintain soil K nutrients and be absorbed and used by apple roots, and at the same time obtain the potential optimal yield. Similarly, apple trees can only absorb and store less K in advance in soils with lacking IKS. Therefore, the potential optimal yield can be obtained only by applying more K fertilizer to supplement soil K nutrients and for apple roots to absorb and utilize.

3. K Use Efficiency and Agronomic Efficiency of K under Different K Input

K use efficiency (KUE) and the agronomic efficiency of K (KAE) are two important indicators for measuring agriculture production sustainability [50][51][52]. **Figure 4** depicts the variation trend of KUE and KAE under different K rates so as to establish their response curves to K rates. Both KAE and KUE in the study area decreased exponentially with an increase in K rates and were comparatively higher under low K application conditions (**Figure 4**). The mean values were 80.97, 93.76 kg kg^{-1} for KUE, and 11.78, 24.13 kg kg^{-1} for KAE in the Loess Plateau and Bohai Bay, which were lower than 145.87, 225.85 kg kg^{-1} for KUE, and 26.02, 29.00 kg kg^{-1} for KAE under the optimal K rates, respectively (**Figure 2**). This fact showed that the estimated Optimum K rate based on the L+P model could not only greatly increase the yield (**Figure 2**) but significantly increase the KAE and KUE (**Figure 4**). This was similar to the conclusion reported by Lammerts van Bueren [53] that NUE was comparatively high at low N rates and reduced with increasing N rates. The high NUE might be due to the higher leaf area index and leaf N concentration, which led to greater accumulation of dry matter and greater N uptake from the soil [54]. In addition, formulating a reasonable amount of K-fertilizer was likely to achieve high KAE under low K levels. Synchronizing K-fertilizer supply with crop K demand through reasonable K-fertilizer regulation will improve both KUE and KAE.

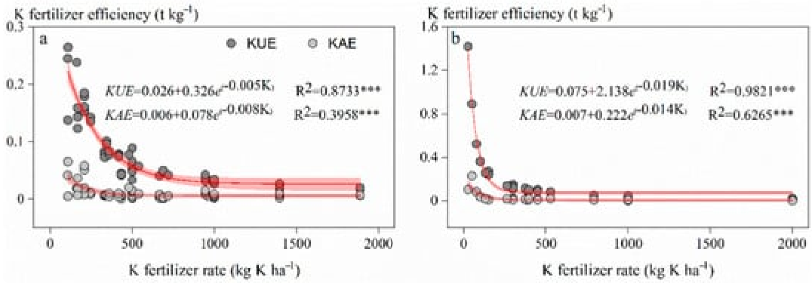

Figure 4. K use efficiency (KUE) and agronomic efficiency of K (KAE) in apple-growing regions of (**a**) China's Loess Plateau and (**b**) Bohai Bay. *** indicates significance at the 0.001 level.

4. Yield and K Fertilizer Efficiency of the Optimum K Rate

An optimal K rate that takes into account both high yield and fertilizer efficiency is what fruit growers hope most in apple production. However, the phenomenon of applying less or more K-fertilizer was more common in most apple orchard management practices. Therefore, we hoped to further elaborate on the importance of optimizing K management in apple production by comparing the differences in yield, KUE, and KAE between high K, optimized K, and low K rates. Firstly, the L + P model was used to calculate the region optimal K rate, and the high K and low K rates were defined as the K-fertilizer application rate higher than and lower than the region optimal K rate. For our research regions, 78.94 and 75.86% of the K application rates were higher than the optimal K rate, and 12.28 and 24.14% were less than the optimal K rate in different K fertilizer treatments at all sites in the Loess Plateau and Bohai Bay, respectively. Then, the average values of all low K and high K treatments in different regions were calculated as representatives of low K and high K fertilizer, respectively. The corresponding yield was calculated by the L+P model, and the corresponding KUE (or KAE) was calculated based on the exponential relationship between K application rates and KUE (or KAE), respectively.

Compared with the yield of low K-fertilizer, the optimal K rate yield increased by 6.03% in the Loess Plateau and Bohai Bay regions. The study by Xu et al. [55] showed that low K-fertilizer inhibited root development by significantly reducing root-shoot ratio, root activity, and the organ biomass of apple trees, thereby reducing yield, while optimal K fertilizer could make carbohydrates transfer from vegetative organs to storage organs by increasing photosynthetic efficiency, carbon and nitrogen metabolism enzyme activities, thereby increasing fruit weight and yield [55][56]. Although the optimal K rate has almost the same yields as the high K rate in all regions (**Figure 5**b), KUE at the optimal K rate enhanced by 45.88 and 70.52% and raised KAE by 68.57 and 77.45% for the Loess Plateau and the Bohai Bay districts, respectively (**Figure 5**c,d). It was fully revealed that a high K application rate not only leads to a serious waste of K resources and increases the financial burden of fruit growers but also may aggravate soil fertility degradation in orchards [57]. Zhang et al. [58] studied the response of fruit quality to K application rate and showed that plenty accumulation of K in the soil was caused by overuse K application during the orchard rest stage. The optimal K rate could assure both a high yield and KUE; a low K-fertilizer rate limited the potentiality for production growth, while a high K-fertilizer rate caused overabundance K in the soil and endangered soil health. The optimal K rate estimated in our study could synergistically improve apple yields and KUE. Therefore, the optimal K rate could be used as advice or reference for K-fertilizer management in apple orchards in the study zones.

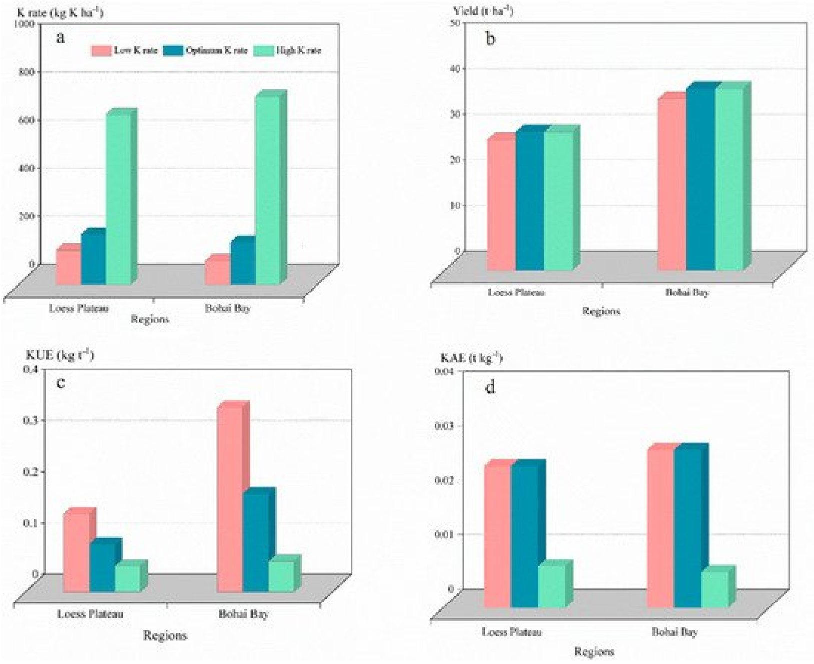

Figure 5. K rate (**a**) apple yield, (**b**) K use efficiency (KUE), (**c**) and agronomic efficiency of K (KAE), (**d**) under three K-fertilizer levels (low K rate, optimal K rate and high K rate) in apple planting regions of China's Loess Plateau and Bohai Bay.

5. Uncertainty of Optimum K Rate

5.1. Based on Different Research Targets

Different research objectives will lead to different optimal K rates, making it clear that the research aim was essential when formulating an optimal K-fertilizer management policy. Allison et al. [59] reported the optimal K rate policy based on response to yield, and Jiang et al. [60] reported the optimal K rate to maximize economic benefits. Crop yield was directly or indirectly involved no matter what kinds of research goals were pursued. Therefore, maximizing crop yield was often regarded as the first goal when determining the optimal K rate [61]. In this study, the optimal K rate was certainly different from that determined by yield if the research goal was to pursue economic income, ecological benefits, social benefits, or other goals [62].

5.2. Based on Specific Sites

The reference K application rate obtained from existing studies with similar soil and climate conditions was reasonable and feasible when making the optimization K-fertilizer management strategies at small-scale fields. However, it was not scientific enough to improve the K-fertilizer management for large-scale regions only by relying on the results obtained from studies conducted in individual sites. The results obtained from different field trials on a regional scale could provide relatively reliable guidance and reference for large-scale regions K-fertilizer management [63]. In our study, the estimated optimal K rate was derived from the comprehensive results of multiple field trials on a regional scale, taking into account the impact of different levels of K application rates. Recommending appropriate K inputs should be adjusted to match the production conditions of specific-site research to account for the differences in uncontrollable factors (e.g., soil and climatic conditions) between different test sites. Jiang et al. [64] conducted a nutritional analysis on apple orchards in three soil types of brown loam, alluvial soil, and brown soil in Shandong Province, China. The results showed that the available K content in brown loam was significantly higher than that in brown soil and significantly lower than that in alluvial soil. Apple trees are not only highly dependent on climatic conditions, especially precipitation, but also extremely sensitive. Drought leads to the deterioration of the soil's physicochemical environment, and apple trees find absorbing required nutrients difficult. When rain causes waterlogging, soil nutrients are easily lost to affect fruit yield. Except for uncontrollable factors, the K application rates should also be mediated on the types of K-fertilizer, timing of K-applied, apple trees species, and management practices [65]. The research results of Feng et al. [66] and Chen et al. [67] both showed that the rational application of KCL fertilizer in apple orchards had a slightly better yield-increasing effect than K_2SO_4. The results of Zhao et al. [62] showed that the combined application of organic fertilizers and chemical fertilizers significantly increased apple yields compared to a single application of chemical fertilizers. Pramod Kumar et al. [68] reported that the rational management of K-fertilizer, fertilizer ratio, and fertilization timing during the apple growth period could obtain a higher yield than that of traditional K-fertilizer. Applying the optimized K management practices could reduce the amount of K-fertilizer needed to achieve the target yield. Based on this, the adjustment of K application rates needed to integrate consideration controllable factors (such as types of K-fertilizer, the timing of K-applied, apple trees species, and management practices) and uncontrollable factors (such as soil and climate) in some specific locations. The unreasonable K application rate (excessive or insufficient K-fertilizer) formulated based on fruit growers' experience rather than K demand for physiological growth of apple trees was widespread and has long been applied in most regions. The over-fertilization of K cannot greatly increase the yield of areas with sophisticated management practices and proper plant conditions, but it will intensify environmental risk and soil degradation in this region. Moreover, we should minimize the input of K-fertilizer in areas with high K application. The negative effect of inadequate K application on yield should also not be neglected [69][70][71]. Reasonably increasing K application rates in some regions with a low IKS or improper climatic conditions will help avoid output loss (Appendix A [72][73][74][75][76][77][78][79][80][81][82][83][84][85][86][87]).

6. Conclusions

Through the comparison and evaluation of five models of the relationship between K application rate and yield for advantageous apple-producing regions of China, the L + P model was established as the best estimation model of the relationship between K application rate and yield at the regional scale, and the optimum K rates for the Loess Plateau and Bohai Bay were estimated to be 208.33 and 176.61 kg K ha^{-1}, respectively. We found that the optimal K rate estimated based on the model significantly improved the KUE and KAE without almost causing apple yield loss. The target yield could be achieved by applying less K-fertilizer in regions with a larger IKS. The apple yield would be reduced by 6.03% when the K application rate was lower than the optimum K rate. Although an equivalent yield could be obtained from the optimum K rate and a high K application rate, the optimal K application rate could improve KUE and KAE by 45.88–68.57% and 70.52–77.45%, respectively. In view of the results, it should be considered wise to moderately reduce K application rate by reference to the optimal K rate in apple planting regions that overuse K-fertilizer, and increase K application rate in low K-fertilizer rate areas to improve apple yield and maintain the sustainable development of soil K-fertilizer fertility. Overall, the assessment of regional K-fertilizer application rates provides evidence for how to coordinate the regulation of optimal K rate management, crop yield maintenance, and sustainable soil fertility.

References

1. Philip, L.F.; Herb, S.A.; Elizabeth, E.D.; James, J.L.; Hokanson, S.C. Collection, Maintenance, Characterization, and Utilizationof Wild Apples of Central Asia. Hort. Rev. 2003, 29, 1–61.
2. Boyer, J.; Liu, R.H. Apple phytochemicals and their health benefits. Nutr. J. 2004, 3, 5.
3. Ulaszewska, M.; Vazquez-Manjarrez, N.; Garcia-Aloy, M.; Llorach, R.; Mattivi, F.; Dragsted, L.O.; Pratico, G.; Manach, C. Food intake biomarkers for apple, pear, and stone fruit. Genes Nutr. 2018, 13, 29.
4. Han, M.Y. Annual Report on the Development of Apple Industrial Technology; MOA: Beijing, China, 2008.
5. FAO. FAOSTAT Production Database; FAO: Rome, Italy, 2016.
6. Godfray, H.C.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food security: The challenge of feeding 9 billion people. Science 2010, 327, 812–818.
7. Inouye, A.M.W. China: Fresh Deciduous Fruit Annual; USDA Foreign Agricultural Service: Washington, DC, USA, 2019.
8. Ma, W.L.; Abdulai, A. Linking apple farmers to markets Determinants and impacts of marketing contracts in China. China Agric. Econ. Rev. 2016, 8, 2–21.
9. Musacchi, S.; Serra, S. Apple fruit quality: Overview on pre-harvest factors. Sci. Hortic. 2018, 234, 409–430.
10. Wang, N.; Wolf, J.; Zhang, F.-S. Towards sustainable intensification of apple production in China—Yield gaps and nutrient use efficiency in apple farming systems. J. Integr. Agric. 2016, 15, 716–725.
11. Kim, S.O.; Chung, U.R.; Kim, S.H.; Choi, I.M.; Yun, J.I. The Suitable Region and Site for 'Fuji' Apple Under the Projected Climate in South Korea. Korean J. Agric. Forest Meteorol. 2009, 11, 162–173.
12. Zhang, Q.; Zhou, B.B.; Li, M.J.; Wei, Q.P.; Han, Z.H. Multivariate analysis between meteorological factor and fruit quality of Fuji apple at different locations in China. J. Integr. Agric. 2018, 17, 1338–1347.
13. Li, W.; Yang, M.; Wang, J.; Wang, Z.; Fan, Z.; Kang, F.; Wang, Y.; Luo, Y.; Kuang, D.; Chen, Z.; et al. Agronomic Responses of Major Fruit Crops to Fertilization in China: A Meta-Analysis. Agronomy 2019, 10, 15.
14. Liu, C.W.; Sung, Y.; Chen, B.C.; Lai, H.Y. Effects of nitrogen fertilizers on the growth and nitrate content of lettuce (Lactuca sativa L.). Int. J. Environ. Res. Public Health 2014, 11, 4427–4440.

15. Pettigrew, W.T. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol. Plant 2008, 133, 670–681.

16. Ashley, M.K.; Grant, M.; Grabov, A. Plant responses to potassium deficiencies: A role for potassium transport proteins. J. Exp. Bot. 2006, 57, 425–436.

17. Prajapati, K.; Modi, H.A. The importance of potassium in plant growth–A review. Indian J. Plant Sci. 2012, 1, 177–186.

18. Qi, J.; Sun, S.; Yang, L.; Li, M.; Ma, F.; Zou, Y. Potassium Uptake and Transport in Apple Roots Under Drought Stress. Hortic. Plant J. 2019, 5, 10–16.

19. Cakmak, I. Potassium for better crop production and quality. Plant Soil 2010, 335, 1–2.

20. Nava, G.; Dechen, A.R. Long-Term Annual Fertilization with Nitrogen and Potassium Affect Yield and Mineral Composition of 'Fuji' Apple. Sci. Agric. 2009, 66, 377–385.

21. Basile, B.; Reidel, E.J.; Weinbaum, S.A.; DeJong, T.M. Leaf potassium concentration, CO2 exchange and light interception in almond trees (Prunus dulcis (Mill) D.A. Webb). Sci. Hortic. 2003, 98, 185–194.

22. Bednarz, C.W.; Oosterhuis, D.M. Physiological changes associated with potassium deficiency in cotton. J. Plant Nutr. 1999, 22, 303–313.

23. Cassman, K.G.; Kerby, T.A.; Roberts, B.A.; Bryant, D.C.; Brouder, S.M. Differential Response of Two Cotton Cultivars to Fertilizer and Soil Potassium. Agron. J. 1989, 81, 870–876.

24. Marschner, P. Marschner's Mineral Nutrition of Higher Plants. In Marschner's Mineral Nutrition of Higher Plants; Marschner, P., Ed.; Academic Press: Cambridge, MA, USA, 2012.

25. Oosterhuis, D.M.; Loka, D.A.; Kawakami, E.M.; Pettigrew, W.T. The Physiology of Potassium in Crop Production. Adv. Agron. 2014, 126, 203–233.

26. Suelter, C.H. Enzymes activated by monovalent cations. Science 1970, 168, 789–795.

27. Wang, Y.; Wu, W.H. Potassium transport and signaling in higher plants. Annu. Rev. Plant Biol. 2013, 64, 451–476.

28. Teo, G.; Suziki, Y.; Uratsu, S.L.; Lampinen, B.; Ormonde, N.; Hu, W.K.; DeJong, T.M.; Dandekar, A.M. Silencing leaf sorbitol synthesis alters long-distance partitioning and apple fruit quality. Proc. Natl. Acad. Sci. USA 2006, 103, 18842–18847.

29. Malvi, U. Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka J. Agric. Sci. 2011, 24, 106–109.

30. Sheldrick, W.F.; Syers, J.K.; Lingard, J. Soil nutrient audits for China to estimate nutrient balances and output/input relationships. Agric. Ecosyst. Environ. 2003, 94, 341–354.

31. Andrist-Rangel, Y.; Edwards, A.C.; Hillier, S.; Öborn, I. Long-term K dynamics in organic and conventional mixed cropping systems as related to management and soil properties. Agric. Ecosyst. Environ. 2007, 122, 413–426.

32. Hoa, N.; Janssen, B.; Oenema, O.; Dobermann, A. Comparison of partial and complete soil K budgets under intensive rice cropping in the Mekong Delta, Vietnam. Agric. Ecosyst. Environ. 2006, 116, 121–131.

33. Sardans, J.; Peñuelas, J. Potassium: A neglected nutrient in global change. Global Ecol. Biogeogr. 2015, 24, 261–275.

34. Savci, S. Investigation of Effect of Chemical Fertilizers on Environment. APCBEE Proc. 2012, 1, 287–292.

35. Jemrić, T.; Fruk, I.; Fruk, M.; Radman, S.; Sinkovič, L.; Fruk, G. Bitter pit in apples: Pre- and postharvest factors: A review. Span. J. Agric. Res. 2016, 14, 15.

36. Liu, M.Y.; Song, L.Q.; Zhao, L.L. Occurrence and prevention of apple bitter pit. Yantai Fruits 2019, 2, 34–35.

37. Sun, L.Y.; Gao, R.S.; Qin, S.J. Research Progress on the Occurrence and Integrated Control of Apple Bitter Pit. North. Fruits 2021, 1, 1–3.

38. Wu, X.; Wang, D.; Riaz, M.; Zhang, L.; Jiang, C. Investigating the effect of biochar on the potential of increasing cotton yield, potassium efficiency and soil environment. Ecotoxicol. Environ. Saf. 2019, 182, 109451.

39. Dhillon, J.S.; Eickhoff, E.M.; Mullen, R.W.; Raun, W.R. World Potassium Use Efficiency in Cereal Crops. Agron. J. 2019, 111, 889–896.

40. Rengel, Z.; Damon, P.M. Crops and genotypes differ in efficiency of potassium uptake and use. Physiol. Plant 2008, 133, 624–636.

41. Li, H.T.; Zhou, J.B.; Wen, X.W.; Dang, T.; Ma, W.Z.; Lei, Z.X. The effect of nitrogenous, phosphatic, and potassium fertilizers on Fuji Apple Trees. Res. Soil Water Conserv. 1996, 3, 163–168.

42. Jin, H.C.; Zhang, L.S.; Li, B.Z.; Han, M.Y.; Liu, X.G. Effect of potassium on the leaf nutrition and quality of Red Fuji Apple. Acta Agric. Boreali Occident. Sin. 2007, 16, 100–104.

43. Malo, D.; Schumacher, T.; Doolittle, J. Long-term cultivation impacts on selected soil properties in the northern Great Plains. Soil Tillage Res. 2005, 81, 277–291.

44. Tan, D.; Jin, J.; Jiang, L.; Huang, S.; Liu, Z. Potassium assessment of grain producing soils in North China. Agric. Ecosyst. Environ. 2012, 148, 65–71.

45. Tan, D.; Liu, Z.; Jiang, L.; Luo, J.; Li, J. Long-term potash application and wheat straw return reduced soil potassium fixation and affected crop yields in North China. Nutr. Cycl. Agroecosyst. 2017, 108, 121–133.

46. Zhang, C.Y.; Chang, Q.; Huo, X.X. Analysis on the layout of China's apple production transition. Econ. Geogr. 2018, 38, 141–151.

47. Fernandez, J.A.; DeBruin, J.; Messina, C.D.; Ciampitti, I.A. Late-season nitrogen fertilization on maize yield: A meta-analysis. Field Crops Res. 2020, 247, 107586.

48. Cong, R.; Li, H.; Zhang, Z.; Ren, T.; Li, X.; Lu, J. Evaluate regional potassium fertilization strategy of winter oilseed rape under intensive cropping systems: Large-scale field experiment analysis. Field Crops Res. 2016, 193, 34–42.

49. Jing, Q.; Bouman, B.A.M.; Hengsdijk, H.; Van Keulen, H.; Cao, W. Exploring options to combine high yields with high nitrogen use efficiencies in irrigated rice in China. Eur. J. Agron. 2007, 26, 166–177.

50. Duan, Y.; Zhang, J.; An, H.; Jing, Y.P.; Jin, C.W.; Zhao, N.; Li, S.T. Effectively increasing the yield and oil quality of sunflower by basal application of potassium fertilizers in Hetao irrigation area, Inner Mongolia. J. Plant Nutr. Fertil. 2018, 24, 1349–1356.

51. Hartley, T.N.; Thomas, A.S.; Maathuis, F.J.M. A role for the OsHKT 2;1 sodium transporter in potassium use efficiency in rice. J. Exp. Bot. 2020, 71, 699–706.

52. Olk, D.C.; Cassman, K.G.; Simbahan, G.; Cruz, P.C.S.; Abdulrachman, S.; Nagarajan, R.; Tan, P.S.; Satawathananont, S. Interpreting fertilizer-use efficiency in relation to soil nutrient-supplying capacity, factor productivity, and agronomic efficiency. Nutr. Cycl. Agroecosyst. 1999, 53, 35–41.

53. Van Bueren, E.T.L.; Struik, P.C. Diverse concepts of breeding for nitrogen use efficiency. A review. Agron. Sustain. Dev. 2017, 37, 37–50.

54. Qiang, S.; Zhang, Y.; Fan, J.; Zhang, F.; Xiang, Y.; Yan, S.; Wu, Y. Maize yield, rainwater and nitrogen use efficiency as affected by maize genotypes and nitrogen rates on the Loess Plateau of China. Agric. Water Manag. 2019, 213, 996–1003.

55. Xu, X.; Du, X.; Wang, F.; Sha, J.; Chen, Q.; Tian, G.; Zhu, Z.; Ge, S.; Jiang, Y. Effects of Potassium Levels on Plant Growth, Accumulation and Distribution of Carbon, and Nitrate Metabolism in Apple Dwarf Rootstock Seedlings. Front. Plant Sci. 2020, 11, 904.

56. Wang, Q.; He, W.H.; Guo, J.N.; Huang, X.G.; Jiao, S.M.; He, Y.H. Effect of application of potassium fertilizer on production and fruit quality apple trees. J. Fruit Sci. 2002, 19, 424–426.

57. Kuzin, A.I.; Trunov, Y.V.; Solovyev, A.V. Effect of fertigation on yield and fruit quality of apple (Malus domestica Borkh.) in high-density orchards on chernozems in Central Russia. Acta Hortic. 2018, 1217, 343–350.

58. Zhang, Z.Y.; Li, Y.J.; Cui, W.S.; Liu, M.Y.; Du, X.Z.; Jiang, X.L. Effects of increasing potassium fertilizer on apple fruits and orchard soil. Shandong Agric. Sci. 2013, 45, 97–99, 102.

59. Allison, M.F.; Fowler, J.H.; Allen, E.J. Responses of potato (Solanum tuberosum) to potassium fertilizers. J. Agric. Sci. 2001, 136, 407–426.

60. Jiang, W.T.; Liu, X.H.; Wang, Y.; Zhang, Y.; Qi, W. Responses to Potassium Application and Economic Optimum K Rate of Maize under Different Soil Indigenous K Supply. Sustainability 2018, 10, 2267.

61. Vos, J. Nitrogen Responses and Nitrogen Management in Potato. Potato Res. 2010, 52, 305–317.

62. Zhao, Z.P.; Yan, S.; Liu, F.; Ji, P.H.; Wang, X.Y.; Tong, Y.A. Effects of chemical fertilizer combined with organic manure on Fuji apple quality, yield and soil fertility in apple orchard on the Loess Plateau of China. Int. J. Agric. Biol. Eng. 2014, 7, 45–55.

63. Liu, Y.; Ma, J.; Ding, W.; He, W.; Lei, Q.; Gao, Q.; He, P. Temporal and spatial variation of potassium balance in agricultural land at national and regional levels in China. PLoS ONE 2017, 12, e0184156.

64. Yuanmao, J.; Manru, G.; Huairui, S. Nutrient diagnosis of starking delicious' apple. Acta Hortic. Sin. 1995, 22, 215–220.

65. Roberts, T.L. Improving nutrient use efficiency. Turk. J. Agric. Forest. 2008, 32, 177–182.

66. Feng, S.K.; Yang, S.C.; Nie, H.R. Preliminary report on application techniques of potassium fertilizer in apple orchard on sloping land in Western Liaoning. China Fruits 1987, 4, 38–40.

67. Chen, C.; Tong, Y.A.; Lu, Y.L.; Gao, Y.M. Effects of different potassium fertilizers on production, quality and storability of Fuji apple. J. Plant Nutr. Fertil. 2016, 22, 216–224.

68. Kumar, P.; Sharma, S.K.; Kumar, A. Foliar nutritive fluids affect generative potential of apples: Multilocation DOP indexing and PCA studies under dry temperate agro-climatic conditions of north-west Himalaya. Sci. Hortic. 2017, 218, 265–274.

69. Hou, Y.L. Theory and technological system of ecological balanced fertilization. Acta Ecol. Sin. 2000, 20, 653–658.

70. Hou, Y.L. Theory system, index system of ecological balanced fertilization and demonstration for fertilizer efficiency evaluation. J. Agroenviron. Sci. 2011, 30, 1257–1266.

71. Yan, J.C.; Lei, H.Z. The development tendency and inspiration of ecological agriculture in the world. World Agric. 2005, 1, 7–10.

72. An, F.S.; Xing, Q.M.; Zhao, Q.; Sheng, X.F.; Cui, L.X. Study on Application of Biological Potash Fertilizer in Apple Orchard. Yantai Fruits 1997, 4, 15–17.

73. An, F.Z.; Zhang, F.S. Effects on yield and quality in close planting apple orchard with potash fertilization. South. Hortic. 2012, 23, 16–18.

74. Feng, S.K.; Yang, R.L.; Nie, H.R. Comparative experiment of two kinds of potassium fertilizer on apple fertilizer efficiency. North. Fruits 1989, 3, 19–21.

75. Feng, Z. Effect of Different Potassium Levels on the Yield and Quality of Red Fuji Apple. Anhui Agric. Sci. Bull. 2015, 3, 56–57.

76. Gao, Y.M.; Tong, Y.A.; Lu, Y.L.; Wang, X.Y. Effects of Soil Available Nutrients and Long-term Fertilization on Yield of Fuji Apple Orchard of Weibei Area in Shaanxi, China. Acta Hortic. Sin. 2013, 40, 613–622.

77. Li, T.T.; Zhai, B.N.; Li, Y.G.; Liu, L.L.; Han, M.Y. Effect of fertilizer type on growth and yield of Fuji apple in Weibei dry region of Shaanxi. J. Fruit Sci. 2013, 30, 591–596.

78. Lin, H.T.; Jiang, L.H.; Liu, Z.H.; Song, X.Z.; Zheng, F.L.; Wang, M.; Zhang, W.J. Effects of applying potassium magnesium sulfate on apple yield, quality and leaf mineral nutrition. Shandong Agric. Sci. 2007, 6, 86–88.

79. Liu, R.L.; Tong, Y.A.; Gao, Y.M.; Zhao, Y. Study on soil nutrients in apple orchard and balanced fertilization in shaanxi Weibei dry-land. J. Northwest Sci-Tech Univ. Agric. For. 2008, 36, 135–140.

80. Shi, C.Y. Effects of Different NPK Treatments on the Yield of Luochuan Red Fuji Apple. Shanxi Agric. Econ. 2017, 5, 57–59.

81. Tang, X.R.; Zhang, F.Q. Effect of Potassium Fertilizer Application on Fruit Yield and Quality in Apple Orchard. Yantai Fruits 2007, 3, 19–20.

82. Zhang, L.X.; Geng, Z.C.; Li, S.X. Research on interaction between water and different forms of potassium and quality responses of Fuji apple on Weibei rainfed highland. Acta Univ. Agric. Boreali-occident. 2002, 30, 21–26.

83. Zhang, P.P.; Xu, X.Y.; Qiu, D.X.; Zang, M.J. Application of kalium fercilizer in palm soil increases the yield and improves the quatoty of various crops. J. Shandong Agric. Univ. 2003, 34, 424–426.

84. Zhao, Z.P.; Duan, M.; Tong, Y.A. Effects of different fertilizations on yield and fruit quality of Fuji apple in different ecological regions. Agric. Res. Arid Areas 2016, 34, 158–165.

85. Zhao, Z.P.; Tong, Y.A. Effect of different fertilization on apple yield, fruit quality and storage duration of Fuji apple. J. China Agric. Univ. 2016, 21, 26–34.

86. Zhao, Z.P.; Tong, Y.A.; Gao, Y.M.; Fu, Y.Y. Effect of different fertilization on yield and quality of Fuji apple. J. Plant Nutr. Fertil. 2005, 19, 1130–1135.

87. Zheng, W.; Li, Y.; Gong, Q.; Zhang, H.; Zhao, Z.; Zheng, Z.; Zhai, B.; Wang, Z. Improving yield and water use efficiency of apple trees through intercrop-mulch of crown vetch (Coronilla varia L.) combined with different fertilizer treatments in the Loess Plateau. Span. J. Agric. Res. 2016, 14, 30.