# Analysis on Wheat Yield in China Based on the Prediction of Yield Potential

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**Abstract** The maximum yield growth range of wheat yield per unit in China is analyzed from three aspects including photosynthesis production potential of wheat, the changing trend of per unit wheat in the previous years and potential of distribution area agricultural crops. In the paper, the potential of using light, the external potential of historical yield evolution tend and AEZ (agricultural ecological zone) are applied to calculate the per unit yield potential of Chinese wheat. The results assume that the maximum growth range of per unit yield in different stages was different: before 1991, the growth range was 10%; before 1996, the growth range was 9%; before 2000, the growth range was 8%. Any variety of wheat and planting technology higher than the above growth range can only be promoted in restricted area and has the statistical error. The results are of reference significance to Chinese wheat production.

**Key words** Wheat, Production potential, Yield per unit, China

The yield potential of crops refers to the possible maximum yield of crops through human efforts to overcome a certain restriction factor, several restriction factors or all restriction factors. With the yield potential of crops, the academic circle has conducted widespread research[1-5]. Wheat is one of the major food crops in China (especially in northern area). With the continuous increase of Chinese population and ever declining farmland, the yield increase potential of wheat, improved seeds of high yield crops and cultivation of high yield crops have attracted more and more attention. Therefore, analyzing the yield increase level of wheat in different periods according the yield potential of wheat is of great significance to the improvement and cultivation of high yield species of wheat.

## 1 Prediction on the potential of wheat yield per unit

**1.1 Production potential of photosynthesis** Through photosynthesis, crops can produce dry matter. Therefore, basically, improving the light use efficiency is the best way to improve the yield potential of crops. At present, the known plant, which has highest use rate of light is napier grass (4.2%) in Salvador (tropic), the crops with the highest light use rate are England and American corn (3.4%). In temperate zone, for example, Holland, the light use rate of wheat is 1.7%[2]. That is to say, taking the highest light use rate in plant as the limitation, the largest photosynthesis yield potential of wheat is 2.5 times more than the current level. China is trying to explore the high yield of wheat in production practice. For example, in 2008, the new species of cross-breeding wheat "Xiza No.5" has achieved the 498 kg/hm$^2$, which created a new record of wheat experiment in Shaanxi Province[6]. In 2008, the yield per unit of wheat created a new record with the yield of 10 018.5, 318.0 kg/hm$^2$ more than that of the previous years[7]. The total yield of wheat in Henan Province from 1949 to 2007 has increased 8.8 times and the per unit yield has increase 7.1 times[8]. Since the foundation of China, the wheat species in Henan Province has finished eight times of update. The per unit yield has increased from 645 kg/hm$^2$ in the primary period of Chinese foundation to 5 235 kg/hm$^2$ in 2005[9]. In 2008, the per unit yield of wheat in Jiaozuo City, Henan Province has broken through 7 500 kg/hm$^2$ and the wheat yield in the high yield demonstration has broken through 9 000 kg/hm$^2$ and the wheat yield in yield-breaking field has broken through 7 500 kg/hm$^2$[10]. In 2009, the National Wheat Engineering Research Center adopts the cultivation and management technology of narrow row and close planting, which created the highest record of wheat average yield 10 251 kg/hm$^2$[11].

**1.2 The evolution trend of Chinese wheat yield per unit over the years** The evolution trend of yield per unit of Chinese wheat from 1961 to 2010 can be seen on Fig.1 (the full line is the actual yield curve and the dotted line is the trending line).

Taking the year as independent variable ($X$), yield per unit as dependent variable ($Y$), we conduct regression fitting on wheat production over the years, the fitting degree of a cubic equation (S curve) is high ($R^2 = 0.906^{**}$)[5]. Besides, since 1994, the interest of Chinese major crops (price rate of production and investment) has begun to decrease and has not returned, which indicated that the interest rate (marginal interest divides marginal costs) has surpassed the maximum value. The yield per unit increase rate of crops has surpassed the maximum point, that is the second inflection point of S curve[4-5]. That is to say, from the evolution trend of Chinese

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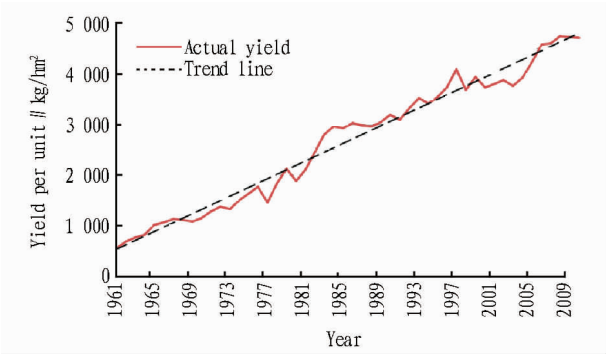


**Fig. 1 Evolution trend of Chinese wheat per unit yield over the years**

wheat yield per unit in the previous years, its yield per unit potential of wheat is 2 to 3 times of the yield in large area of wheat production.

**1.3 The potential of wheat yield per unit in farming system district on the basis of AEZ model** On the basis of Chinese farming system district, the wheat potential in 41 sub-districts of Chinese farming system area is calculated by using the AEZ model (Agro-ecological Zone) jointly developed by United Nations Food and Agriculture Organization (FAO) and International Institute for Applied Systems Analysis (IIASA, under the GIS platform.

The basis of AEZ model is the compound index equation of Mitscherlich-Baule[12]:

$$Y=[(1-e^{-b_1-a_1X_1})-N]\cdots[(1-e^{-b_n-a_nX_n})-N] \quad (1)$$

In equation (1), $Y$ is the yield, $a$ and $b$ are crop parameters, $1\cdots\cdots n$ are the contribution factor of crop yield and $N$ is the yield potential of crops.

Calculating the regional yield potential of wheat is to divide the region to several small units with 5 $km^2$ per unit in two dimensional spaces to calculate the weight average value of all units. The farmland is divided into rain-fed fields and irrigated one, the equation is as follows.

$$Y_I^R=\sum_{ij\in CSZ}S_{ij}A_{ij}Y_{ij}^{IR}/\sum_{ij\in CSZ}S_{ij}A_{ij} \quad (2)$$

In equation (2), $Y$ is the yield potential of crops (t/$hm^2$), $I$ refers to crops, $R$ means rain-fed, $i$ refers to horizontal unit series, $j$ refers to vertical unit series, $S$ means the area proportion(%) and $A$ refers to farmland area($hm^2$).

$$Y_I^I=\sum_{ij\in CSZ}S_{ij}A_{ij}Y_{ij}^{II}/\sum_{ij\in CSZ}S_{ij}A_{ij} \quad (3)$$

In equation(3): $Y$ is the yield potential of crops (t/$hm^2$), $I$ is crops, $I$ means irrigated, $i$ is horizontal unit series, $j$ is vertical unit series, $S$ refers to the area proportion(%), $A$ is the area of farmland($hm^2$).

*CSZ* represents the Cropping systems zone in farming system.

The prediction result shows that the highest potential of Chinese wheat yield per unit is mainly distributed in southern Loess Plateau, Fen-wei valley and Qing-ba mountainous area with the area of 8.7 to 9.3 t/$hm^2$, two or three times more than the wheat yield per unit in large area of production[13]. It can be regarded as the limit of regional wheat yield per unit to a large degree in China.

## 2 Analysis on Chinese wheat yield per unit

The above three prediction results show that Chinese wheat yield per unit is two or three times more than the large area per unit in production. In China, every year, there are many new wheat varieties and each new species is claimed to increase 10% of the yield on the basis of the original major varieties(or else the new varieties can not get the approval. It is regarded that every year there is a new wheat variety with the yield increase rate of 10%, that is to say, the annual yield increase rate of wheat in China is at least 10%, Taking Chinese wheat yield per unit (559 kg/$hm^2$) in 1961 as a base, and calculating according to the annual increase rate from 1% to 10%, and then by 2010, the theoretical wheat yield per unit in China is shown on Table 1:

**Table 1 The theoretical value of Chinese per unit wheat yield under different annual growth rate from 1962 to 2010** kg/$hm^2$

| Year | Actual yield | Theoretical value of wheat yield under different growth rate | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
| 1962 | 694 | 565 | 570 | 576 | 581 | 587 | 593 | 598 | 604 | 609 | 615 |
| 1963 | 778 | 570 | 582 | 593 | 605 | 616 | 628 | 640 | 652 | 664 | 677 |
| 1964 | 822 | 576 | 593 | 611 | 629 | 647 | 666 | 685 | 704 | 724 | 744 |
| 1965 | 1 022 | 582 | 605 | 629 | 654 | 680 | 706 | 733 | 761 | 789 | 819 |
| 1966 | 1 059 | 588 | 617 | 648 | 680 | 714 | 748 | 784 | 822 | 860 | 900 |
| 1967 | 1 128 | 593 | 630 | 668 | 707 | 749 | 793 | 839 | 887 | 938 | 990 |
| 1968 | 1 115 | 599 | 642 | 688 | 736 | 787 | 841 | 898 | 958 | 1 022 | 1 090* |
| 1969 | 1 086 | 605 | 655 | 708 | 765 | 826 | 891 | 961 | 1 035 | 1 114 | 1 198 |
| 1970 | 1 148 | 611 | 668 | 729 | 796 | 867 | 945 | 1 028 | 1 118 | 1 214 | 1 318 |
| 1971 | 1 272 | 618 | 682 | 751 | 828 | 911 | 1 001 | 1 100 | 1 207 | 1 324 | 1 450 |
| 1972 | 1 370 | 624 | 695 | 774 | 861 | 956 | 1 061 | 1 177 | 1 304 | 1 443 | 1 595 |
| 1973 | 1 334 | 630 | 709 | 797 | 895 | 1 004 | 1 125 | 1 259 | 1 408 | 1 573 | 1 755 |
| 1974 | 1 512 | 636 | 723 | 821 | 931 | 1 054 | 1 193 | 1 347 | 1 521 | 1 714 | 1 930 |
| 1975 | 1 640 | 643 | 738 | 846 | 968 | 1 107 | 1 264 | 1 442 | 1 642 | 1 868 | 2 123 |
| 1976 | 1 775 | 649 | 752 | 871 | 1 007 | 1 162 | 1 340 | 1 543 | 1 774 | 2 037 | 2 335 |
| 1977 | 1 465 | 656 | 768 | 897 | 1 047 | 1 220 | 1 420 | 1 651 | 1 915 | 2 220 | 2 569 |
| 1978 | 1 845 | 662 | 783 | 924 | 1 089 | 1 281 | 1 506 | 1 766 | 2 069 | 2 420 | 2 826 |

Continued(Table 1)

| Year | Actual yield | Theoretical value of wheat yield under different growth rate | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% |
| 1979 | 2 140 | 669 | 799 | 952 | 1 133 | 1 346 | 1 596 | 1 890 | 2234 | 2 637 | 3 109 |
| 1980 | 1 891 | 675 | 815 | 980 | 1 178 | 1 413 | 1 692 | 2 022 | 2413 | 2 875 | 3 419 |
| 1981 | 2 109 | 682 | 831 | 1 010 | 1 225 | 1 483 | 1 793 | 2 164 | 2 606 | 3 133 | 3 761 |
| 1982 | 2 452 | 689 | 847 | 1 040 | 1 274 | 1 558 | 1 901 | 2 315 | 2 814 | 3 415 | 4 137 |
| 1983 | 2 802 | 696 | 864 | 1 071 | 1 325 | 1 636 | 2 015 | 2 477 | 3 040 | 3 723 | 4 551 |
| 1984 | 2 969 | 703 | 882 | 1 103 | 1 378 | 1 717 | 2 136 | 2 650 | 3 283 | 4 058 | 5 006 |
| 1985 | 2 937 | 710 | 899 | 1 137 | 1 433 | 1 803 | 2 264 | 2 836 | 3 545 | 4 423 | 5 507 |
| 1986 | 3 040 | 717 | 917 | 1 171 | 1 490 | 1 893 | 2 400 | 3 034 | 3 829 | 4 821 | 6 058 |
| 1987 | 2 983 | 724 | 936 | 1 206 | 1 550 | 1 988 | 2 544 | 3 247 | 4 135 | 5 255 | 6 663 |
| 1988 | 2 968 | 731 | 954 | 1 242 | 1 612 | 2 087 | 2 696 | 3 474 | 4 466 | 5 728 | 7 330 |
| 1989 | 3 043 | 739 | 973 | 1 279 | 1 677 | 2 192 | 2 858 | 3 717 | 4 823 | 6 244 | 8 063 |
| 1990 | 3 194 | 746 | 993 | 1 318 | 1 744 | 2 301 | 3 029 | 3 978 | 5 209 | 6 805 | 8 869 |
| 1991 | 3 100 | 754 | 1 013 | 1 357 | 1 813 | 2 416 | 3 211* | 4 256 | 5 626 | 7 418 | 9 756** |
| 1992 | 3 331 | 761 | 1 033 | 1 398 | 1 886 | 2 537 | 3 404 | 4 554 | 6 076 | 8 086 | 10 732 |
| 1993 | 3 519 | 769 | 1 054 | 1 440 | 1 961 | 2 664 | 3 608 | 4 873 | 6 562 | 8 813 | 11 805 |
| 1994 | 3 426 | 776 | 1 075 | 1 483 | 2 040 | 2 797 | 3 825 | 5 214 | 7 087 | 9 606 | 12 985 |
| 1995 | 3 542 | 784 | 1 096 | 1 527 | 2 121 | 2 937 | 4 054 | 5 579 | 7 654 | 10 471 | 14 284 |
| 1996 | 3 734 | 792 | 1 118 | 1 573 | 2 206 | 3 084 | 4 297 | 5 969 | 8 266 | 11 413** | 15 712 |
| 1997 | 4 102 | 800 | 1 141 | 1 620 | 2 295 | 3 238 | 4 555 | 6 387 | 8 928 | 12 441 | 17 283 |
| 1998 | 3 685 | 808 | 1 163 | 1 669 | 2 386 | 3 400 | 4 828 | 6 834 | 9 642 | 13 560 | 19 012 |
| 1999 | 3 947 | 816 | 1 187 | 1 719 | 2 482 | 3 570 | 5 118 | 7 313 | 10 413 | 14 781 | 20 913 |
| 2000 | 3 738 | 824 | 1 210 | 1 771 | 2 581 | 3 749* | 5 425 | 7 825 | 11 246** | 16 111 | 23 004 |
| 2001 | 3 806 | 832 | 1 235 | 1 824 | 2 684 | 3 936 | 5 751 | 8 372 | 12 146 | 17 561 | 25 304 |
| 2002 | 3 885 | 841 | 1 259 | 1 879 | 2 792 | 4 133 | 6 096 | 8 958 | 13 118 | 19 141 | 27 835 |
| 2003 | 3 776 | 849 | 1 284 | 1 935 | 2 903 | 4 340 | 6 462 | 9 585 | 14 167 | 20 864 | 30 618 |
| 2004 | 3 932 | 858 | 1 310 | 1 993 | 3 019 | 4 556 | 6 849 | 10 256 | 15 301 | 22 742 | 33 680 |
| 2005 | 4 252 | 866 | 1 336 | 2 053 | 3 140 | 4 784 | 7 260 | 10 974 | 16 525 | 24 789 | 37 048 |
| 2006 | 4 593 | 875 | 1 363 | 2 114 | 3 266 | 5 024 | 7 696 | 11 742 | 17 847 | 27 020 | 40 753 |
| 2007 | 4 608 | 884 | 1 390 | 2 178 | 3 396 | 5 275 | 8 158 | 12 564 | 19 274 | 29 452 | 44 828 |
| 2008 | 4 762 | 893 | 1 418 | 2 243 | 3 533 | 5 539 | 8 647 | 13 443 | 20 817 | 32 102 | 49 311 |
| 2009 | 4 739 | 902 | 1 446 | 2 310 | 3 674 | 5 816 | 9 166 | 14 384 | 22 482 | 34 992 | 54 242 |
| 2010 | 4 730 | 911 | 1 475 | 2 379 | 3 821 | 6 107 | 9 716 | 15 391 | 24 281 | 38 141 | 59 666 |

Date source: *Chinese Agricultural Yearbook* and FAO website.

It can be seen from Table 1 that according the annual increase rate from 1% to 4%, from 1962 to 2010, the theoretical Chinese wheat yield per unit was always lower than the actual yield per unit but the annual increase rate was too low; according to the annual growth rate of 5%, after 2000, the theoretical value of Chinese wheat yield per unit will steadily surpass the actual yield per unit(it is represented in Table 1by ,the following is the same); according to the annual growth rate of 6%, after 1991, the theoretical value of Chinese wheat yield per unit will surpass the actual yield per unit; according to the annual growth rate of 7%, after 1986, the theoretical value of Chinese wheat yield per unit would be stable and surpass the actual yield; according to the annual growth rate of 8%, after 1973, Chinese wheat yield per unit would be stable and surpass actual yield per unit; according to the annual growth rate of 10%, the theoretical value of Chinese wheat yield per unit would be stable and surpass the actual yield per unit. That is to say, from 1961 to 2010, the annual growth rate of Chinese wheat yield with large area was: 10% before 1968, 9% before 1969, 8% before 1973, 7% before 1986, 6% before 1991 and 5% before 2000, any statistics bigger than the above growth rate would have errors. That is to say, the smaller the annual growth rate of wheat yields per unit, the more difficult the growth of wheat growth per unit.

According to the prediction of Chinese wheat yield per unit, the highest growth rate of Chinese wheat yield production(typical high yield) in different periods can be predicted from the rate of theoretical yield to actual yield per unit. Taking the upper bound of potential of Chinese wheat yield per unit (three times of the yield per unit in large production area ) as an example, in different periods, the highest annual growth rate of Chinese wheat was 10% before 1991(represented by in Table 1), 9% before 1996 and 8% before 2000. Any report of growth rate higher than the above rate is only the special high yield variety or cultivation technology, not the variety and cultivation. The improvement of total output of Chinese yield should rely on improving the yield per unit of middle and low production field, not on the typical high yield fields.

## 3 Conclusions and discussions

There are many ways for improving crop production and production potential. Improving any metabolic mechanism of crop can improve its yield, for example, improving the water use rate of crops can get high yield. The yield potential of crops can be divided into two kinds: the first one is the internal potential

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and the second one is the external potential. The internal potential of crop yield refers to the highest yield that can be probably obtained through changing the internal genetic factors and genetic mechanism. The external potential refers to the highest yield obtained probably through overcoming the blocking factors in the growth environment. Through variety cultivation and genetic engineering, the yield of crops can be improved obviously. So far, it is regarded as the most effective way for improving yield potential of crops.

The significances of improving the variety of high yield wheat rely on improving the yield per unit and stabilizing features of yield. Through many years' planting, the high yield feature of a variety will separate from each other, which will lead to the low yield. The improved seeds and advanced cultivation should support each other. An improved seed should go with advanced cultivation technology to get high yield. Cultivation technology is the external appearance of high yield feature. No matter what seed improving approaches (for example cloning) or cultivation technology(for example controllable temperature), the yield per unit potential of crops is limited, for the solar radiation on each area of field is limited. The low yield and high quality is twin legacy of crops, but the high yield and high quality is a contradictory pair. Quality is the restriction factor of quantity to a certain degree, or else. It is the natural law that should be obeyed. It is undeniable that under special situation, there might be the typical of high yield wheat, but it can not last long. This kind of variety and cultivation technology can not be use widely. So, when making the aim of improving and cultivating wheat yield, the natural laws should be obeyed with science and reason.

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