Crop Monitoring as an
E-agricultural tool in
Developing Countries

CGMS STRATEGY REPORT FOR ANHUI

An analysis of yield determining factors for winter-wheat in Anhui

Reference: *E-AGRI_Deliverable23.2_StrategyReport_1.0*

Author(s): Allard de Wit, Zhiyi Zhou

Version: 1.0

Date: 13/03/2013

DOCUMENT CONTROL

Signatures

Author(s) : Allard de Wit, Zhiyi Zhou

Reviewer(s) : Qinghan Dong

Approver(s) :

Issuing authority :

Change record

Release	Date	Pages	Description	Editor(s)/Reviewer(s)
1.0	13/03/2013	41	CGMS Strategy report for Anhui	
2.0				

TABLE OF CONTENT

LIST OF FIGURES

EXECUTIVE SUMMARY

The WOFOST crop simulation model that is embedded into the Crop Growth Monitoring System (CGMS) only simulates crop growth under potential and water-limited conditions while other yield limiting factors (nutrients, pests, disease) are missing. The original area of application of CGMS was Western-Europe where crops are grown under well-managed conditions and this limitation was not apparent. Within the E-Agri project, the Crop Growth Monitoring System is rolled out to Anhui province in China. The physiological principles that are implemented in WOFOST will not be different in Anhui. However, yield limiting factors beyond those implemented in WOFOST may be different from conditions in Western Europe and may be an important driver of crop yield variability. In this deliverable the results from a survey are reported that was carried out in order to understand the agricultural system in Anhui and its main drivers of yield variability.

The results from our survey demonstrate that the winter-wheat yield variability, yield level and yield trend in Anhui province are the results of a complex, often interrelated set of factors. With regard to the inter-annual yield variability, direct weather factors such as drought, water logging of the soil, low sunshine hours and frost certainly play a role. However, on top of these direct weather factors, indirect effects are important as well with key roles for harvest problems, disease and pests caused by large rainfall amounts in combinations with many rainy days (high humidity) and low sunshine hours. Finally the effects of agricultural policy, improved wheat cultivars and improved field management by farmers have not only resulted in an upward trend in crop yield since 2005, but have also resulted in decreased yield variability.

With regard to the implementation of CGMS for winter-wheat simulation in Anhui, we recommend to 1) Implement CGMS in Anhui using a single variety. The effects of disease cannot be taken into account in CGMS anyway and this simplifies setting up and calibrating CGMS considerably. 2) Test the effect of enabling oxygen stress in CGMS. 3) Define additional agro-meteorological indicators to estimate the impact of disease and pests and implement these in the E-Agri viewers and the CGMS level 3. The indicators defined in chapter 5 can be start, although indicators based on relative humidity should be investigated. 4) Include remote sensing based indicators in the CGMS level3 tool as these indicators may better reflect the actual situation at the field and may thus better quantify the crop yield.

1. Introduction

The WOFOST crop simulation model that is embedded into the Crop Growth Monitoring System (CGMS) only simulates crop growth under potential and water-limited conditions. This means that the inter-annual variability in crop yield as simulated by WOFOST is mainly determined by variability in the temperature, radiation and amount of rainfall as a results of weather variability. Out of the many additional yield limiting factors causing yield variability, only few can be taken into account by CGMS/WOFOST (e.g. oxygen stress) while other factors such as nutrient limitation, harvest losses, pests and disease are currently not taken into account.

The original area of application of CGMS was Western-Europe where crops are grown under well-managed conditions in terms of fertilizer and pest control, where soils are relatively well-managed and where yields are relatively high. Therefore the focus on yield limiting factors that are weather related was sufficient and there was no urgency for including additional yield limiting factors such as nutrients and pest/diseases. Moreover, these limitations in WOFOST were compensated by a statistical system (the so-called CGMS level 3, see E-Agri WP6), assuming that the yield limiting factors caused an “average” difference between simulated and observed yields that could be treated as bias. This statistical approach had the additional advantage that it automatically takes into account the large differences that occur as a result of CGMS simulating dry matter while the regional yield statistics provide fresh weight (including water content).

Within the E-Agri project, the Crop Growth Monitoring System is rolled out to other regions of the World, notably Morocco and Anhui province in China. The basic physiological principles that are implemented in WOFOST will not be different in different areas of the World, although the WOFOST model must be properly calibrated for the specific crop cultivars that are grown in these regions. However, yield limiting factors (beyond those implemented in WOFOST) may be different from conditions in Western Europe and may be an important driver of crop yield variability in those regions. For example, damp and humid conditions that may occur in certain years in regions in China can be an important driver of fungal diseases spoiling the grain yield of cereal crops. In large regions of Russia, frost kill can be an important factor in certain years and lack of machinery or man power can be an important constraint on harvesting.

It is therefore important to make a survey in order to understand the agricultural system and its main drivers of yield variability. Within e-Agri this survey was planned to be reported in the CGMS strategy reports for the test sites in Morocco and Anhui province. For the Moroccan test sites, it was concluded after discussion with the Moroccan partners that the situation is relatively simple and that rainfall variability is the most important driver of yield variability. Therefore, our analysis focused on improving the CGMS/WOFOST response to rainfall variability as water limitation on crop yield itself is already included in CGMS/WOFOST. This analysis is reported in Deliverable D22.2 with large improvements in the yield prediction performance of CGMS.

For Anhui province, the situation is much more complex as a result of a totally different agricultural system (high input, double cropping), different weather patterns (dry winter, wet summer) and agricultural developments resulting from development programs of the Chinese government. Thus for a successful implementation (and possibly adaptation) of CGMS/WOFOST but also the statistical system there is a need to find out what the main drivers are of wheat yield variability. Gathering this information has been accomplished in three ways:

1. The existing (mainly Chinese) literature on winter-wheat cultivation in Anhui and surrounding provinces was reviewed.
2. A questionnaire was designed and circulated among Chinese researchers to gather information on important factor determining yield variability
3. A short analysis was carried out comparing meteorological data for stations in Anhui with statistical data available for the statistical regions in Anhui (See deliverable D22.1)

2. Literature review on winter-wheat cultivation in Anhui

2.1. Anhui province and Huaibei plain

The study area is the main agricultural production area in the North of the Anhui province in China, called the Huaibei plain (Figure 2 and Figure 3). Anhui province is one of the least developed regions in China. However, due to its geographic location and the prevailing climate, agriculture in Anhui province is extremely diversified and occupies an important place in China (E-AGRI, 2011). The wheat sowing area of the province is on the fourth position of the country at provincial level. Winter wheat is one of the main agricultural products in the north of the province. There are 2.14 million hectares of arable land in Huaibei Plain, and more than 70% of the arable land is used for producing winter wheat (AHNW, 2012). Chinese and international literature as well as general news items were searched to give an insight of the impact factors of inter-annual yield variability in Anhui Province and surrounding regions with similar climate and agricultural practices.

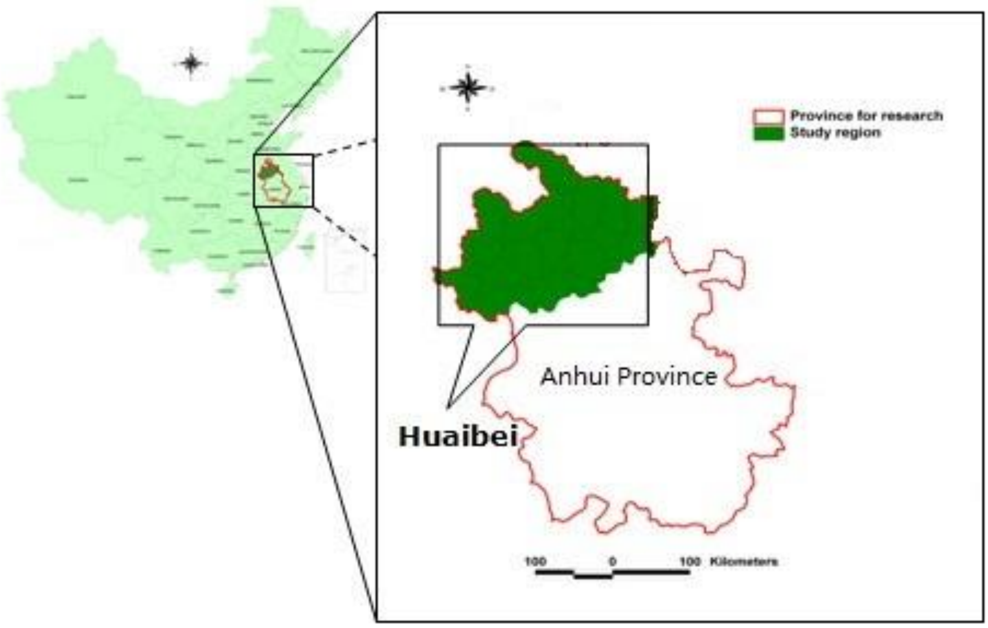


Figure 1. Location of Huaibei Plain in China.

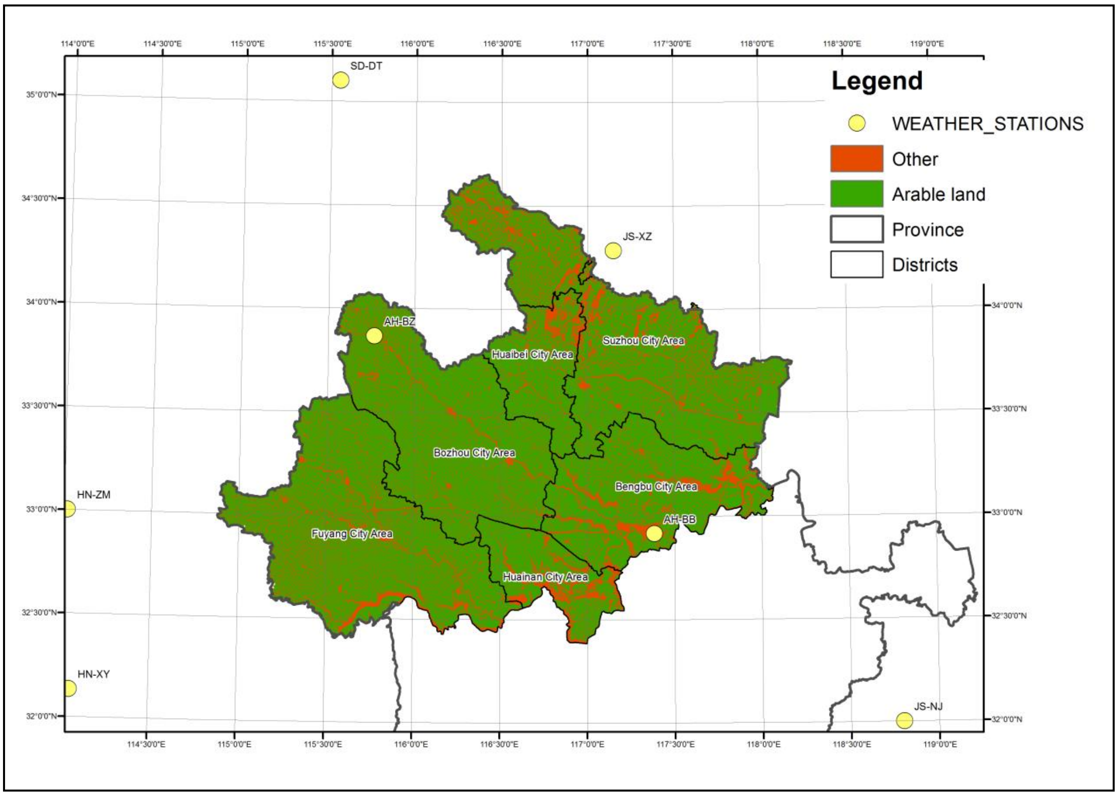


Figure 2. The location of study area and surrounding weather stations.

2.2. Extreme weather and climate events

The Huaibei Plain is located in the north-south climatic transition zone at mid-latitudes. The cold and warm air masses alternate frequently. Anomalous atmospheric circulation occurs often. The number of droughts and floods that occurred in Anhui has been among the most devastating of the whole country. Inter-annual variability of agricultural yields is well known to depend on the weather (Chen et al., 2004).

2.2.1. Excess precipitation and floods

Anhui is located in the climate transition zone between north and south with a lot of rainy days in spring, which is an important period of winter wheat for grain filling. Waterlogging caused by large precipitation amounts also has a negative effect on yield (Ma, et al., 2003). Waterlogging refers to the saturation of the soil with water that causes oxygen shortage in the root zone. When there is long period of rainy days, the soil becomes saturated with water for a continuous period of time which has a negative effect on plant growth and assimilation.

Also floods are recurring phenomena in the regions causing large damage to winter-wheat. For example, in 1991 a violent flood and waterlogging event occurred in the Huai River drainage basin.

The agricultural loss caused by this flood and waterlogging was 22.0 billion Yuan (RMB) (Shi, 1992). In 1998, a flood caused a reduction in the wheat yield in Nanjing, Jiangsu Province which is near Anhui Province (Mao and Chen, 2010).

In addition, the East Asian rainy season is characterized in some years by a period of persistent precipitation along a persistent stationary front known as the Meiyu front for nearly two months[1]. This so-called “plum rain” is an important weather event which occurs in later spring and beginning of summer in Yangtze River Basin and Huai River Basin of China, and it causes waterlogging. When the plum rain comes early, it will affect the late development of maturation and harvest of winter wheat (Yu et al., 2009).

2.2.2. Drought

However, drought also occurs in Anhui province. Drought is frequently occurring in the winter, spring and autumn in the north of the winter wheat growing area in Anhui (Zhang, et al., 2011). Drought decreases photosynthesis, stomatal conductance, viable leaf area, shoot and grain mass, and weight and soluble sugar content of kernels, but increases plant water-use efficiency. Over 80% of the yield of wheat derives from photosynthesis during maturation, suggesting that grain growth is affected by a reduction in the photosynthetic process from drought stress (Shah and Paulsen, 2003). Although irrigation practices are being applied the use of water resources in the northern part of Anhui is not very efficient, when precipitation is not sufficient during the winter wheat growth period. The irrigation water of winter wheat is based on groundwater and extracted using motor-pumped wells.

2.2.3. Frost damage

In addition, frost is also threat to the agricultural activity in most of China from the south to the north and the east to the west (Li et al., 2005). Severe frost may cause 30%-50% yield loss (Feng et al., 1985). Huaibei Plain is a part of Huanghuai Plain, and this area is one of the places where frost can have a serious impact. The Huaibei plain is on the southern edge of the winter-wheat cultivation region in China with relatively mild winters. As such, the local cultivars are adapted to the local climate and generally have limited capabilities for hardening and building frost tolerance which makes them susceptible for frost damage particularly in early spring when sudden cold spells can invade the region. Luo et al. (2011) showed that in the Huanghuai Plain mild frost happened frequently and the frequency was about 15% in all years from 1980 to 2006. From 1981 to 2006, the frost occurred more frequently in the northern part than in the southern part of Huanghuai Plain.

2.3. Weed, pest and disease

Wheat scab (*Fusarium Head Blight*, FHB), caused by *Gibberella Zeae (schw.) Petch*, is one of the important factors reducing yield and grain quality in China. It’s a major disease in the winter wheat

[1] http://en.wikipedia.org/wiki/East_Asian_rainy_season

zones in the middle and lower of Huaibei Plain. For example in 2003, Anhui province was hard hit by the disease because of an increase in both the amount of rainfall and the number of rainy days in the wheat flowering stage in 2003, and many popular varieties got very heavy yield losses because of low resistance to FHB. Even some varieties with moderate resistance in normal years showed severe infections with the disease. Wheat scab disease caused 30% to 50% yield loss in Anhui in 2003 (Gan, 2003).

Huo et al. (2012) indicated that in early spring, less rainfall, high temperature and drought accelerates the breeding speed and population growth of some wheat pests (insect infestations). Heavy rainfall and a long period of rainy days in later spring and early summer could be cause a distinct aggravation of some wheat diseases as happened in 2003. Finally, the most severe damage is often inflicted by a combined occurrence of drought during the early stages of growth and large precipitation amounts during the later stages. As this will provide optimal conditions for both fungal diseases and insect infestations

2.4. Field management

Scientific experiments showed that under the same environmental conditions, field management such as planting density, sowing date, nitrogen application, irrigation and other cultivation measures play a vital role for the yield of wheat.

2.4.1. Sowing density

He (2011) reports that Chinese farmers tend to use high sowing density (225 kg/ha to 300 kg/ha seeds) as they assume that this will increase the yield of winter-wheat. However the grain yield per plant actually decreases due to increased competition for resources among the wheat plants (soil moisture, nutrients). Suitable planting density which is lower than normal farmers sowing density (135 kg/ha to 150 kg/ha) can improve the productivity of wheat (He, 2011).

2.4.2. Sowing date

Different varieties of winter wheat have different sowing periods. Appropriate early seeding (sowing around 8th of October) of wheat can extend the time for grain filling and increase the yield (Zhou et al., 2010).

2.4.3. Nitrogen application

Nitrogen is a nutrient winter wheat requires for growing. Different growth stages have different nitrogen application rates. Applying nitrogen in the jointing stage and booting stage of winter wheat (120 kg/ha) can ensure an adequate basis to raise the number of grains and grain weight by increasing the efficiency of photosynthesis. It is an important way to achieve higher yield (Zhou et al., 2010).

2.4.4. Irrigation

As Huaibei Plain is located near the Huai River, the water resource is relatively sufficient compared to other dry area. However droughts occur often in some parts of the region. The irrigation management during the drought period will influence the wheat yield (Zhang et al., 2011). The booting stage is the critical water demand period in wheat growth. Irrigation in the booting stage (60 L/m^2) can reduce the degradation of the flower, improve the seed setting rate and increase the number of grains. Heading stage and filling stage are periods that need most irrigation (60 L/m^2). Applying irrigation 10 to 15 days after flowering stage (45 L/m^2) can ensure the wheat physiological water needs, improve the field microclimate, reduce the effect of hot wind, delay aging of leaves and roots and increase grain weight (Zhou et al., 2010).

2.4.5. Other cultivation measures

Some news reported that in 1997 wheat yield enhanced by 1.11 ton/ha on average in China due to the plastic film covering technology (China Spark Programme, 2010). In 2007, wheat yield reached 9 ton/ha when cultivated in rotation with cucumber in Zaozhuang, Shandong Province (Anhui Agricultural technology, 2007).

2.5. Impact of wheat cultivar changes

The changes in varieties of wheat played a crucial role for wheat yield increase in the past decades. When a variety was used for too many years, the variety characteristics degraded and no longer had the expected yield. In Anhui Province, the evolution of varieties takes almost 10 years per cycle. In most developed countries the evolution cycle is 3 or 4 years. Also some province near Anhui already shortened their wheat evolution cycle to 4 or 5 years. At the beginning of 2000, the varieties used in province near Anhui had changed once. However at that time there weren’t new quality varieties to replace the old ones in Anhui, and some varieties had already been used for more than 10 years, the potential and resistance of those varieties could not meet the production need. From 2005 to 2007, new varieties were used instead of old ones in Anhui little by little. After 2007 new varieties occupied most of the province (Zhang et al., 2009).

2.6. Social economic factors and policy

From 2005, the Government of Anhui province provided the technology and quality seeds to enhance the wheat yield. They sent technicians to the field to supervise the farmers. They put farmers together in groups to discuss aspects of wheat growth and exchange information and set up specialist groups for wheat protection. There was a flood in 2007, low temperature and freezing in 2008 and drought and a long period of low temperature and raining in 2009, but the yield increased to 4.77 ton/ha in 2007, 4.98 ton/ha in 2008 and 5.03 ton/ha in 2009 (Xinhua News Agency, 2010).

3. Questionnaire design

The aim of the questionnaire (Appendix 1) was to collect more information from people who have knowledge about winter wheat yield variability in study area. The questionnaire includes a short introduction, personal information questions, score rating questions, and open questions to the yield figure (Figure 2). At last there are two questions to get permission for further contact with the respondents. The questionnaire will be send by e-mail directly to the target participant, and after receiving responses of the participants, there will be a follow-up contact with the participants about their answers.

3.1. Introduction

The introduction explains the purpose of the questionnaire. There is also a brief description of the e-AGRI project, CGMS and study area. In case the participant wants to know more detail about the project or the questionnaire, the name and e-mail address of the contact person of cooperate institute were given at the end of the introduction.

3.2. Personal information questions

The personal information is collected to be able to contact the participants in the future. Information on the participants' name, working place and experience was asked in this part to get the insight in the reliability of their answers.

3.3. Score rating questions

According to literature review and discussion with Chinese colleagues, the climate is the main factor influencing winter wheat yield in the study area. The climate itself has a direct impact on yield, such as the frost, high temperature extremes. The climate also has an indirect impact by creating a proper environment for pests and diseases which damage on yield. There are many cities and arable farms in Huaibei Plain. Different farms have different field management methods, such as different amounts and different timing for applying fertiliser and irrigation, so the management is also an important factor. In order to summarise the possible causes from the literature review and make the questions shorter and clearer, in the questionnaire a distinction in three categories of impacts factors were made: 1) direct weather factors; 2) indirect weather factors; 3) management factors.

Considering that the size of the study area is nearly 2.14 million hectares, and the weather conditions and management varies in different parts of the region, the questionnaire also included two different scale levels for answers per factor: 1) local impact level and 2) regional impact level. The scale levels refer to the scale of impact of these events. For example, drought often affects large areas, while a hail storm can be devastating for a small area but the effect on the total production of Anhui province can be negligible.

3.4. Open questions to the yield figure and permission for further contact

Before the questions, yield of winter wheat in six different districts of Huaibei Plain from year 2000 to 2009 were shown (Figure 2). The figure shows that the yield of winter wheat varies between years, and in order to know more about why the yields varies between the years and districts, four questions were asked based on the facts that the figure shows: 1) in 2001 the winter wheat yield was lower in Huainan City, but was higher in other cities; 2) in 2003 the yield was lower in all regions and even severe in some regions; 3) from 2004 to 2009 the yield showed an increasing trend.

There are two questions at the end of the questionnaire. The respondents could choose between yes and no to give permission for further contact on getting the result of this questionnaire and/or getting more information about their answers.

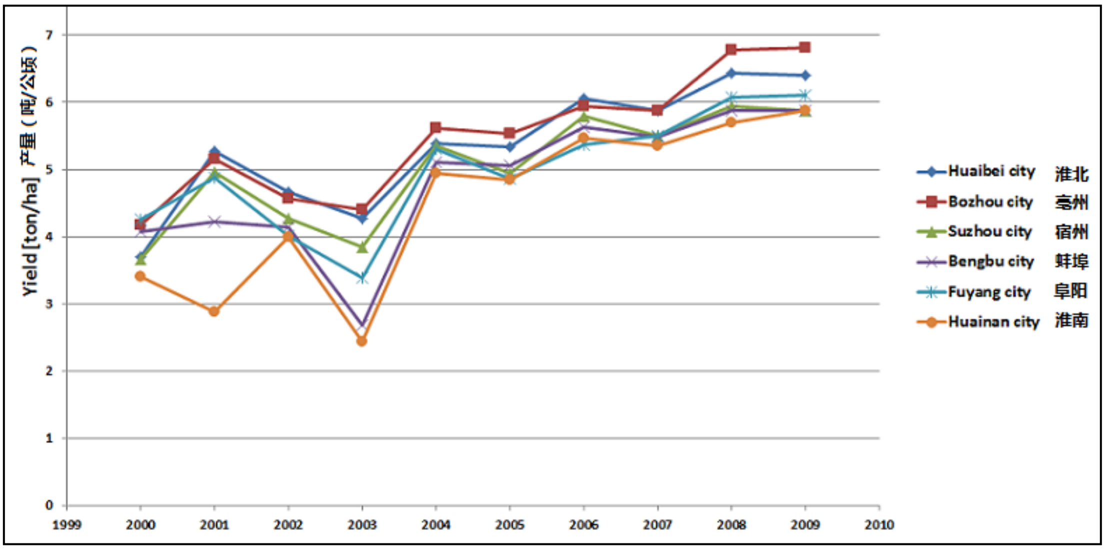


Figure 3. Yield of winter-wheat for 6 different districts in the Huaibei plain in Anhui Province.

3.5. Online questionnaire design and launch tool: QUALTRICS

The questionnaire was made online with QUALTRICS (www.qualtrics.com). It is online survey software which you can easily access and create your own survey. The main reason why this platform was chosen over other well known platforms (e.g. Survey Monkey) was that it is the default platform chosen by Wageningen UR and it has good multi-lingual support including Chinese. The questionnaire was designed in English and then translated to Chinese.

4. Questionnaire responses and results

4.1. Number of responses

The task of distributing of questionnaire was given to partner AIFER as they have the best knowledge on whom to approach in order to collect information. Moreover, it is quite unlikely that many responses would be obtained if the questionnaire was distributed by Alterra to Chinese institutes and respondents that are not familiar with Alterra. The questionnaire was distributed to around 10 people from mainly two organisations:

- Knowledgeable colleagues at the AIFER institute, also those working on crop monitoring through remote sensing.
- Professors and lecturers at the Anhui Agricultural University.

Unfortunately, the number of responses to the questionnaire so far has been limited. In total four questionnaires have been received from people at the AIFER institute itself. From the Anhui Agricultural University so far no responses were received, although some questionnaires from Anhui Agricultural University are still expected by partner AIFER.

4.2. Analysis of the questionnaires

The questionnaires have simply been analysed by counting the scores on the different categories in the questionnaires. No attempts have been made to apply statistical techniques on the results as this has no relevance given the limited number of responses so far.

4.3. Results of impact scoring

According to the questionnaire results the most important direct weather factors are related to *drought* and *flood/waterlogging* with scores from average to high impact (Figure 4). Moreover, these factors are regarded to be important at a regional scale. Additionally, one responded specifically mentions "*continues rainfall during season*" as an additional factor with above average impact. Next *hail* and *lodging* are factors classified as average to above-average impact although generally regarded to be only locally important. Finally, *heat waves* and *frost* are generally regarded as average impact operating mostly on a local scale.

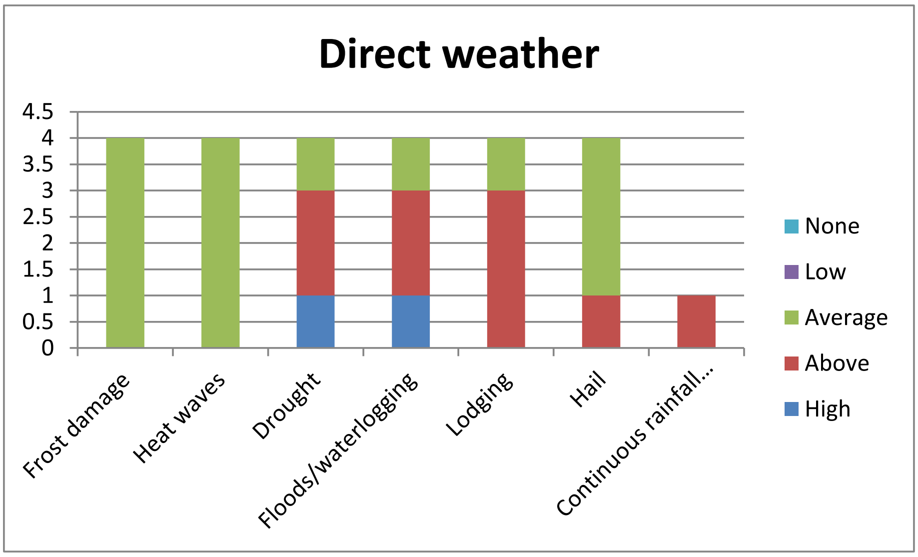


Figure 4. Results of scoring on the categories on direct weather impacts.

According to the questionnaire results the most important indirect weather factors are *disease* and *sowing problems* which are scored mostly as above average impact operating both at local and regional scales depending on the respondent. *Harvest losses* and *pest* infestations are still regarded as important factors but with somewhat lower impact. In terms of spatial scale only the category *harvest losses* is classified as only locally important (maybe due to local soil conditions), while the other are important both at local and regional scale.

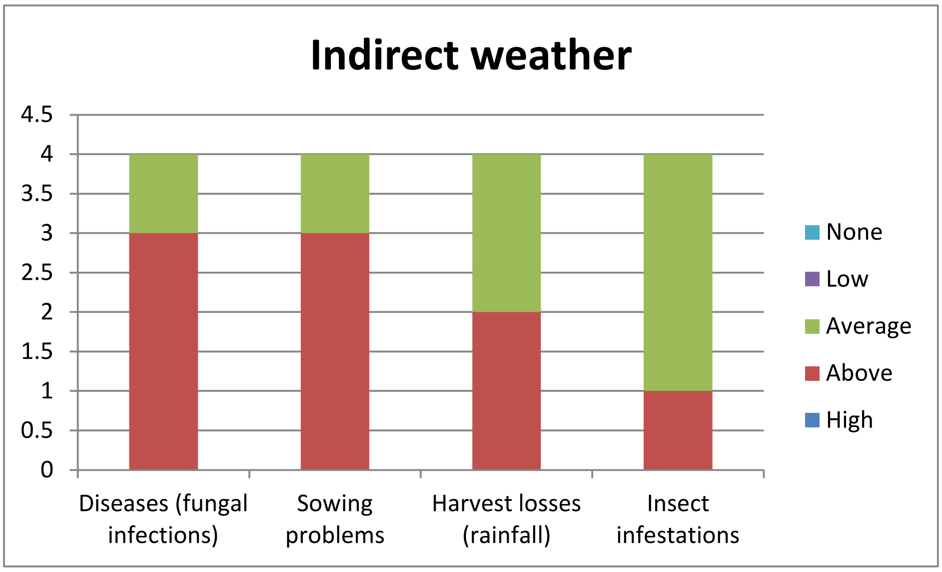


Figure 5. Results of scoring on the categories on indirect weather impacts.

For the scorings on the categories related to crop management, it is interesting to note that all respondents regard the control of pests, weeds and diseases as the least important factor (Figure 6), and only locally important. Application of fertilizer and irrigation regarding timing and amount are have average to above average impact

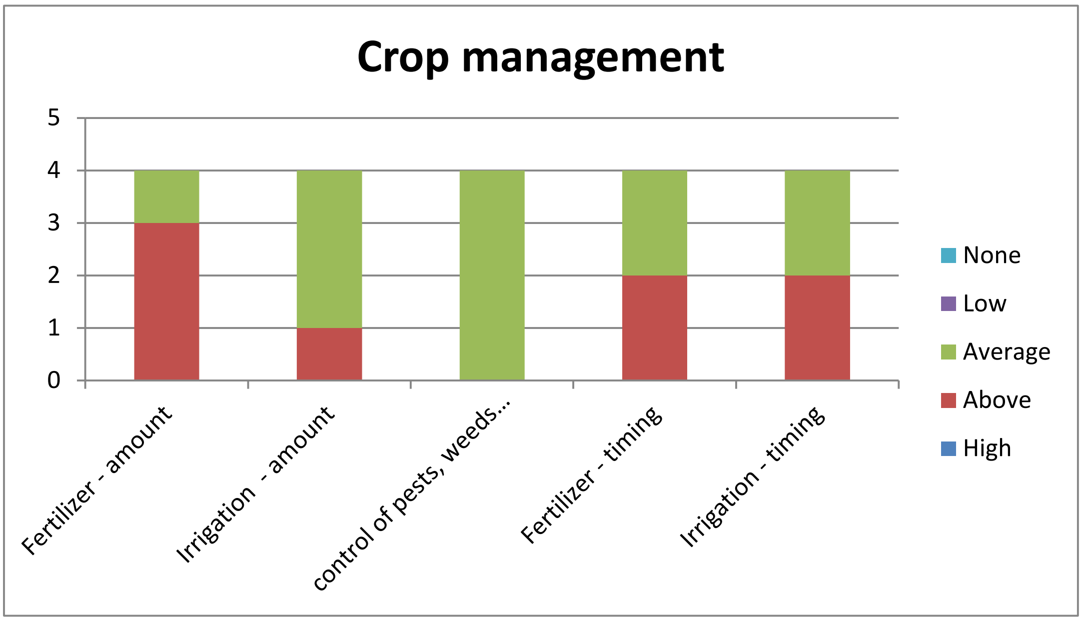


Figure 6. Results of scoring on the categories on crop management

Finally, the last questions in the questionnaire dealt with availability of *man power* and *equipment* (e.g. machinery) and its impact on yield variability. In both cases these factors were regarded to be of above-average impact with availability of *man power* more of local concern, while *equipment* being more of a general impact in the entire region.

Additional, respondents noted some other additional factors that were high impact and of relevance at regional scale:

1. Seed quality
2. Science and technology improvements and technology transfer to farmers
3. Agricultural policies relevant to farmers.

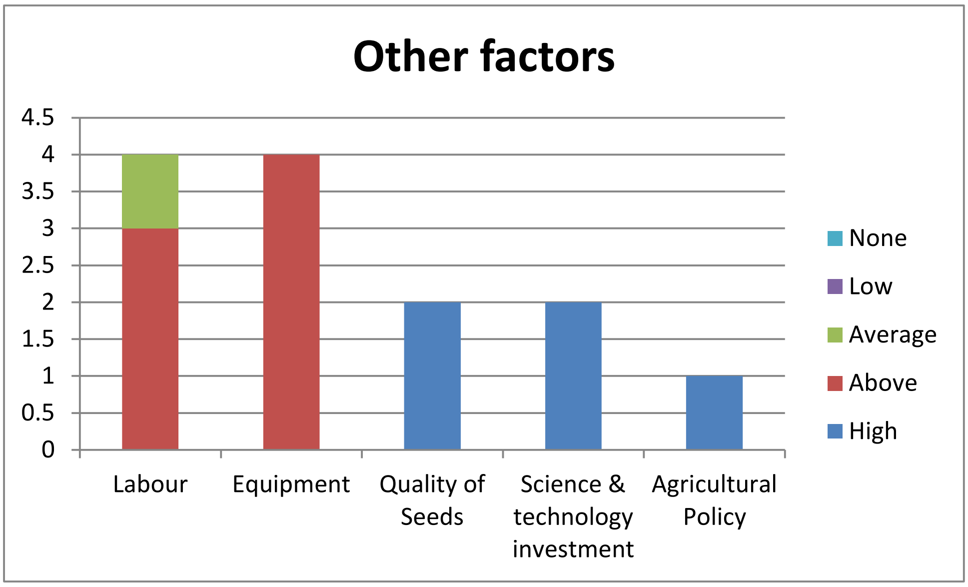


Figure 7. Results of scoring on the categories on Other Factors

4.4. Results of open questions

The open questions in the questionnaire were related to the historical yield variability for the different districts in the north of Anhui province (Figure 3).

The first question was related to the wheat yield in Huainan district in 2001, which was low compared to the other districts in North Anhui. All respondents answered that the origins behind the relatively low yield in 2001 in Huainan district were unclear.

The second question was related to the low wheat yield in 2003 which affected all districts in Northern Anhui. The answers provided by the different respondents were very consistent and can be summarized as:

- A very wet season with low temperatures, a large number of rainy days and a large impact of pests and diseases over almost entire Northern Anhui.
- Large amounts of rainfall during the harvest period causing harvest problems.

Finally, the respondents were asked to reflect on the origins of the increasing yield in Anhui since 2004 and the reduced yield variability over that period. Several interesting answers were provided:

- A change in agricultural policies with reduced taxes for farmers.
- Related to the previous point there is an increase in investments in agriculture in Anhui (and in China in general).

- Developments in science and technology resulting in better disease resistant crop cultivars.
- Improved field management skills by farmers caused by agricultural development programs from the central government.
- Favourable weather conditions during this period.

5. Analysis on yield-weather relationships

The results from literature review and the questionnaire give a rather consistent picture of the factors for yield variability of winter-wheat in Anhui. Major factors decreasing the crop yield are the occurrence of drought as well as problems caused by continues rainfall and high humidity resulting in water logging, diseases and harvest problems. Based on the literature, the impact of frost was recognized as an important factor although this was not confirmed by the questionnaire results. In terms of yield level and the evolution of the yield level over time, it was demonstrated from both the literature review and questionnaire results that investments in agriculture had a positive influence resulting in better cultivars and crop management from around 2005 onward thereby decreasing yield variability.

We carried out a simple analysis to determine if the findings could be confirmed from the regional crop yield statistics and available meteorological data for Northern Anhui. Climate data of three climate stations and yield data of six districts in the study area from 2000 to 2009 were used.

The three weather stations are: 1) AH-BZ (Anhui, Bozhou); 2) JS-XZ (Jiangsu, Xuzhou) and 3) AH-BB (Anhui, Bengbu). The six districts are: 1) Bozhou City Area; 2) Fuyang City Area; 3) Huaibei City Area; 4) Suzhou City Area; 5) Bengbu City Area; 6) Huainan City Area. Due to the lack of weather stations (Figure 3), two districts shared one weather data set. Bozhou and Fuyang shared AH-BZ weather data, Huaibei and Suzhou shared JS-XZ weather data, Bengbu and Huainan shared AN-BB weather data.

Two main climate factors were picked up for the analysis:

- The effect of frost in winter expressed as the number of days at which minimum temperature is lower than -6°C during the winter period (e.g. the Frost Damage Days). For each year the winter period starts from previous year the 1st December and ends at that year at 24th February (Chen et al., 2006). The more frost damage days a year has, the heavier the occurrence of frost.
- Continuous rain during spring time expressed as the number of rainy days (rain amount > 0 mm per day), average sunshine hours and total rainfall amount in April and May (Ma et al., 2003).

These indicators where visualized as charts showing the number frost damage days (Figure 8), total rainfall amount (Figure 9) number of rainy days (Figure 10) and sunshine hours (Figure 11).

Although based on a limited number of years, the results basically confirm the earlier findings. The number of frost damage days is negatively correlated with the regional crop yield before 2005, with a high number of frost days in 2000 and 2003. Also in 2009, a high number of frost days occurred but this is not reflected by a decrease in the regional crop yield probably as a result of better cold-resistant cultivars.

In terms of rainfall amount, particularly the years 2002, 2003, 2008 and 2009 show above average rainfall amounts, while in 2002 and 2003 this is also reflected in an increase in the number of rainy days and a decrease in the number of sunshine hours. Particularly this combination of large rainfall amounts, high number of rainy days and low sunshine hours seems to be responsible for the relatively low regional crop yields in all districts in 2003 and to a lesser degree in 2002. It is interesting that similar large amounts rainfall in 2008 and 2009 do not have a similar impact on the region yield of winter-wheat. This may be explained by the fact that the large amount of rainfall in 2008/2009 did not coincide with a large number of rainy days and low sunshine hours, but the use of new disease-resistant cultivars since 2005 probably also plays a role.

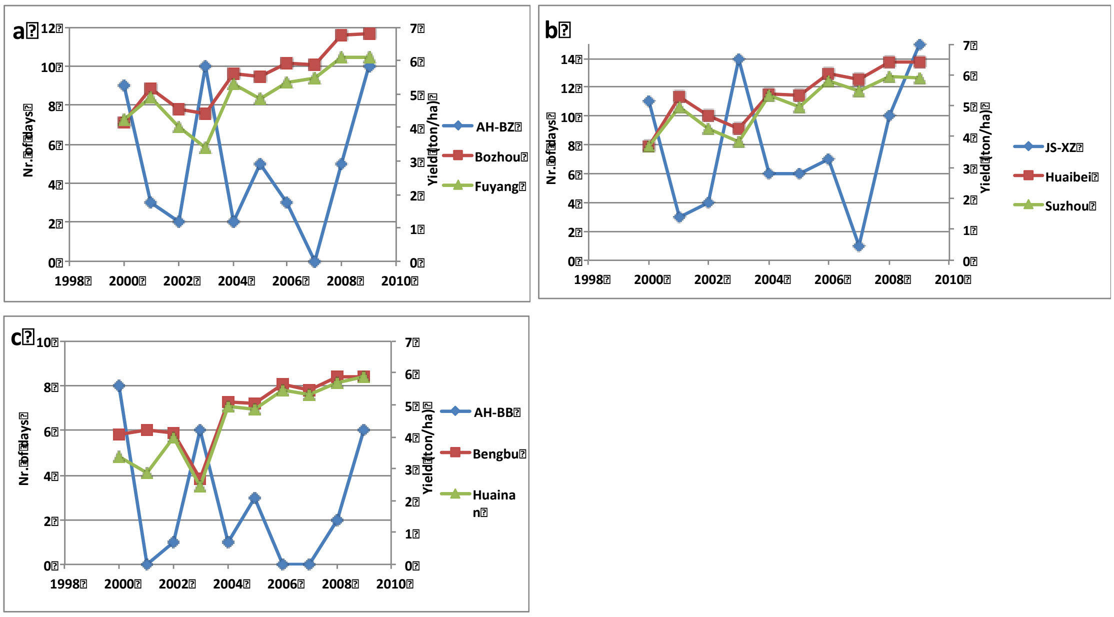


Figure 8. Frost damage days of three different weather stations and winter wheat yield of six districts from 2000 to 2009.

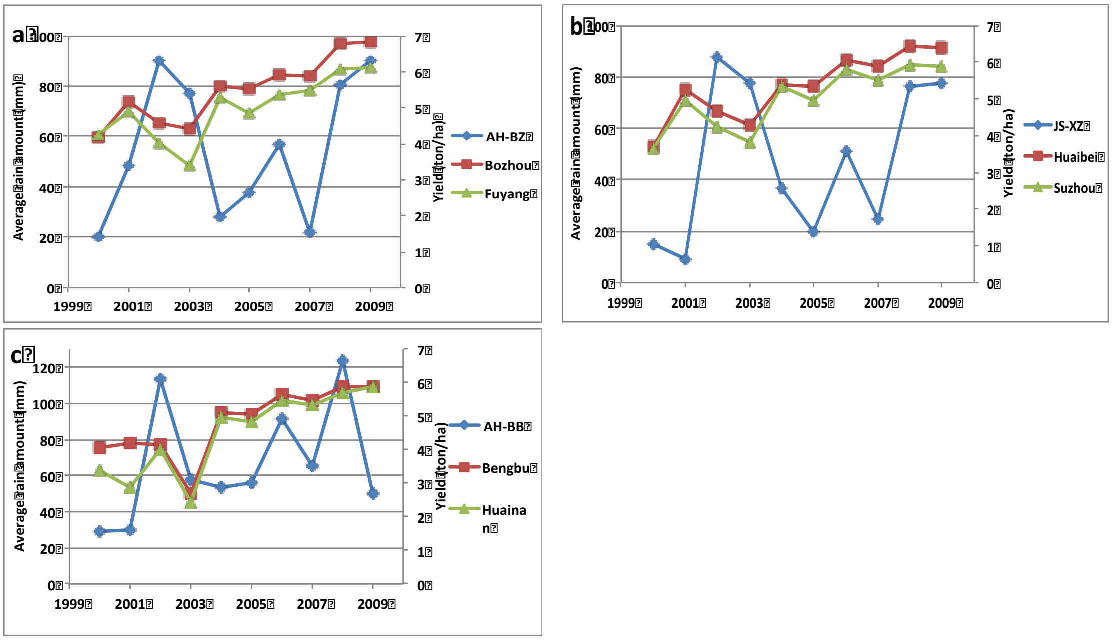


Figure 9. Average monthly rainfall amount over the months April and May of three different weather stations and winter wheat yield of six districts from 2000 to 2009.

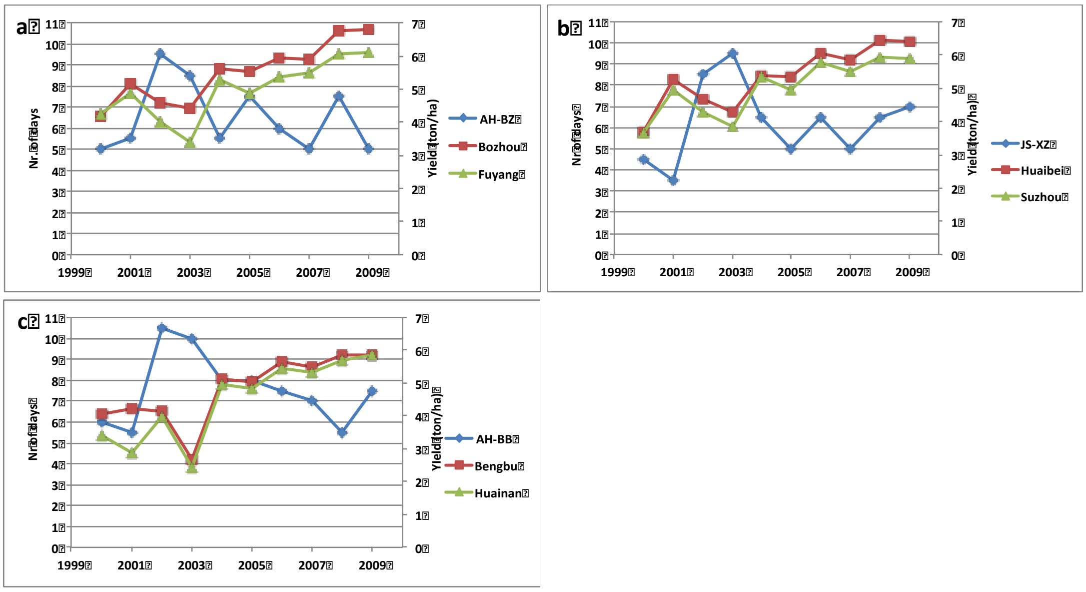


Figure 10. Monthly average number of rainy days over the months of April and May of three different weather stations and winter wheat yield of six districts from 2000 to 2009.

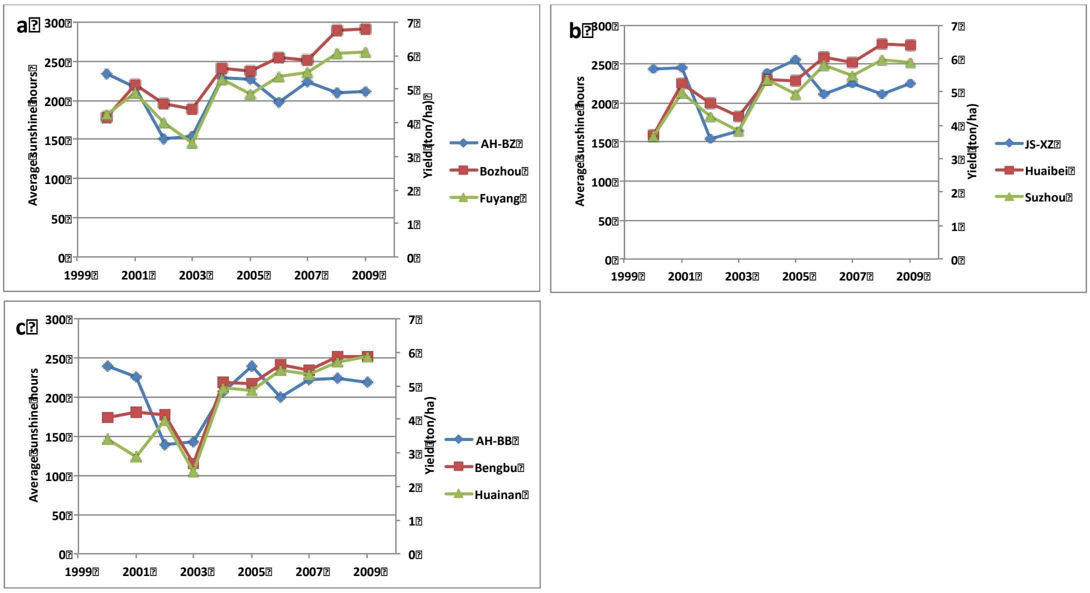


Figure 11. . Average monthly sunshine hours in April and May of three different weather stations and winter wheat yield of six districts from 2000 to 2009.

6. Conclusions and recommendations for CGMS Anhui

The results from our analysis demonstrate that the winter-wheat yield variability, yield level and yield trend in Anhui province are the results of a complex, often interrelated set of factors. With regard to the inter-annual yield variability, direct weather factors such as drought, water logging of the soil, low sunshine hours and frost certainly play a role. However, on top of these direct weather factors, indirect effects are important as well with key roles for harvest problems, disease and pests caused by large rainfall amounts in combinations with many rainy days (high humidity) and low sunshine hours. Finally the effects of agricultural policy, improved wheat cultivars and improved field management by farmers have not only resulted in an upward trend in crop yield since 2005, but have also resulted in decreased yield variability.

With regard to the application of CGMS level2 (crop simulation) and level 3 (statistical system), Anhui is a challenging environment for several reasons. First of all, the impact of direct weather factors (temperature, radiation, precipitation) is taken into account by the WOFOST crop simulation model. Besides drought also water-logging and oxygen stress can be important in Anhui and it thus makes sense to include oxygen stress into the simulation. On the dry side of the soil moisture regime (e.g. drought) the WOFOST model has shown to be able to estimate the impact of water shortage on crop yield well (De Wit et al, 2010). However, on the wet side of the soil moisture regime (e.g. oxygen stress due to water logging) the impacts are less clear. The main reason is that the approach used for calculating drought and oxygen stress (the so-called Feddes trapezoid – Feddes et al. 1978) is less well founded on the wet regime compared to the dry regime (Bartholomeus et al. 2008). Moreover, the oxygen stress option in CGMS/WOFOST is not enabled in the European CGMS setup and its impact may strongly depend on soil hydraulic properties which are poorly known for the FAO soil map used in Anhui.

Second, the impact of disease and pests on crop yield is not taken into account by CGMS. Nevertheless, our results demonstrate that this is important in Anhui in particular for the period 2000-2005. The biophysical approach would be to include a complete disease model in CGMS but this is certainly not feasible within the time-frame of the e-Agri project. The alternative option is to define indicators derived from meteorological and/or crop simulation as a surrogate for the level of disease in wheat. A similar approach can be used for the impact of frost damage.

Third, the change in wheat cultivars since 2005 has some implications for the calibration of CGMS. Technically, CGMS is capable of simulating with different crop varieties over time.

However, the data for calibration of WOFOST is lacking which makes it impossible to understand which cultivar differences are of relevance to WOFOST. A positive effect is that the cultivars that are being used since 2005, are more disease resistant which means that the production levels of WOFOST are becoming more representative of the actual situation (see the chapter 1 - introduction).

Finally, the statistical system (e.g. the CGMS level3) that is used for actual yield prediction searches for a relationship between time-series of past yield statistics and crop yield indicators. These crop yield indicators consist of crop simulation results or meteorological indicators, for example the number of rainy days. If a relationship is found through regression or scenario analysis, it can be used to forecast the yield of the current season. A prerequisite for using this technique is that the relationship between indicators and yield statistics is table over time. The latter is certainly not the case in Anhui, due to the improvement in cultivars since 2005. This complicates the use of the statistical approach implemented in the CGMS level 3.

With regard to the implementation of CGMS for winter-wheat simulation in Anhui, we recommend the following:

- Implement CGMS in Anhui using a single variety. The effects of disease cannot be taken into account in CGMS anyway and this simplifies setting up and calibrating CGMS considerably.
- Test the effect of enabling oxygen stress in CGMS.
- Define additional agro-meteorological indicators to estimate the impact of disease and pests and implement these in the E-Agri viewers and the CGMS level 3. The indicators defined in chapter 5 can be start, although indicators based on relative humidity should be investigated.
- Include remote sensing based indicators in the CGMS level3 tool (e.g. the CGMS Statistical Toolbox) as these indicators may better reflect the actual situation at the field and may thus better quantify the impact.

References

AHNW, 2012. Introduction of Anhui agricultural districts. [online] Available at: <http://www.ahnw.gov.cn/2006nykj/iframe.asp?c=3&ntype=3#h2>. [Accessed on 14 December 2012] (In Chinese)

Anhui Agricultural Technology, 2007. Crop rotation between wheat and cucumber. [online] Available at: <http://www.ahnw.gov.cn:5800/2006nykj/html/200706/%7B0411D0A4-426A-4943-95F3-9A3C05376355%7D.shtml> [Accessed 14 September 2012] (In Chinese)

Bartholomeus, R. P., Witte, J.-P. M., van Bodegom, P. M., van Dam, J. C., Aerts, R., Oct. 2008. Critical soil conditions for oxygen stress to plant roots: Substituting the feddes-function by a process-based model. Journal of Hydrology 360 (1-4), 147-165. URL http://dx.doi.org/10.1016/j.jhydrol.2008.07.029

E-AGRI, 2011. [online] Available at: <http://www.e-agri.info>. [Accessed on 14 December 2012]

China Spark Programme, 2010. Plastic film covering technology in wheat cultivation.[online] Available at: <http://www.ahsp.org.cn/0content_nykj.asp?ID=%7B49F7B950-AE14-40C2-A6D5-3BDCDDAC7890%7D>. [Accessed 14 September 2012] (In Chinese)

Chen, C., McCarl, B.A., Schimmelpfennig, D.E.,2004. Yield variability as influenced by climate: a statistical investigation. Climatic Change, 66, 239–261.

Feddes, R.A., P.J. Kowalik, H. Zaradny. 1978. Simulation of field water use and crop yield. Simulation Monographs Pudoc, Wageningen (1978) 189pp

Feng, P., Li, C., Li, X., 1985. Analysis of major meteorological disasters in China. Beijing, China Meteorological Press, 58-62, 137-139. (In Chinese)

Gan, B., 2003. The Prevalence of Wheat Scab in Anhui Province and the Countermeasures. Journal of Anhui Agricultural Sciences, 3. (In Chinese)

Huo, Z., Li, M., Wang, L., Xiao, J., Huang, D., Wang, C., 2012. Impacts of Precipitation Variations on Crop Diseases and Pests in China. Scientia Agricultura Sinica, 45(10), 1935-1945. (In Chinese)

Li, M., Wang, D., Zhong, X., Wang, C., Su, C., Zhao, P., Yan, X., Chiribuchi-Otobe, C., Yoshida, H., 2005. Current situation and prospect of research on frost of winter wheat. Journal of Natural Disaster, 14(4), 72-78. (In Chinese)

Luo, X., Zhang, Y., Sun, Z., Du, K., Song, G., 2011. Spatial and temporal distribution of winter wheat frost injury in Huanghuai Plain. Chinese Agricultural Science Bulletin, 27(18), 45-50. (In Chinese)

Ma, X., Chen, X., Sheng, S., 2003. Models of evaluating waterlogging loss of winter wheat in Anhui Province. Journal of natural disasters, 12 (1), 158-162. (In Chinese)

Mao, C., Chen, Y., 2010. Climate change and its impact on winter wheat output in Nanjing during recent 60 years. Resources Science, 32(10), 1955-1962. (In Chinese)

Shah, N.H., Paulsen, G.M., 2003. Interaction of drought and high temperature on photosynthesis and grain-filling of wheat. Plant and Soil, 257, 219–226. (In Chinese)

Shi, P.,1991. Flood and waterlogging and strategy to reduce disaster issue of rural area in Huaihe drainage basin of China. Journal of Geography, 47(5), 385-393. (In Chinese)

Xinhua News Agency, 2010. To break the vicious circle of every disaster will be less yield-Interpretation wheat yield increment in China by a quarter which contributed by Anhui Province. [online] Available at: < http://www.gov.cn/jrzg/2010-09/14/content_1702384.htm> [Accessed 14 September 2012]. (In Chinese)

Yu, J., Huang, X., Yu, Y., Guo, X., Dong, B., Lu, T., Wang, H., 2009. Analysis on the new index of plum rains intensity and its spatio-temporal characteristics: a case study on the reaches of the region along Huaihe River and Anhui Province. Scientia Agricultura Sinica, 42(4), 1325-1330. (In Chinese)

Wit, A.J.W. de; Baruth, B.; Boogaard, H.L.; Diepen, C.A. van; Kraalingen, D.W.G. van; Micale, F.; Roller, J.A. te; Supit, I.; Wijngaart, R. van der (2010). Using ERA-INTERIM for regional crop yield forecasting in Europe. Climate Research 44 (1). - p. 41 - 53.

Zhang, H., Ma, X., Chen, X., Wu, W., 2011. Analysis on vulnerability of winter wheat in Anhui Province based on GIS. Chinese Agricultural Science Bulletin, 27(33), 146-150. (In Chinese)

Zhang, P., Xu, J., Fan, R., Xia, X., Wan, Y., Cao, W., 2009. Evolution analysis of wheat varieties in Anhui. Chinese Agricultural Science Bulletin, 25(23), 195-199. (In Chinese)

Zhou, Q., Huang, C., Wang, B., 2010. Cultivation Techniques for Regulating Effect on Wheat Yield. Chinese Agricultural Science Bulletin, 26(12),98-103. (In Chinese)

Appendix 1: questionnaire for collecting information about factors impacting yield variability of winter-wheat in Anhui, China.

Introduction

The purpose of this questionnaire is to collect information about factors that influence the yield of winter-wheat in Anhui. This will increase our understanding of the causes of inter-annual yield variability of winter wheat in Anhui. This knowledge will be used within the e-AGRI project to propose and implement improvements to the Crop Growth Monitoring System. The e-AGRI project (http://www.e-agri.info) is a Sino-European collaboration project funded by the European 7th Framework Programme (http://ec.europa.eu/research/fp7). One of the objectives of this project is to implement a Crop Growth Monitoring System (CGMS) for monitoring winter-wheat growth and forecasting winter-wheat yield for the Huaibei plain in Anhui province, China. Within e-Agri, several European and Chinese institutes are cooperating, among these the Anhui Institute for Economic Research (AIFER: prof. Ma Zhongbo), the Flemish institute for technology (VITO: Dr. Dong Qinghang, qinghan.dong@vito.be) and the Dutch environmental research institute (Alterra: Dr. Allard de Wit, allard.dewit@wur.nl). Please click on the button below to go to the next page

This questionnaire consists six pages of questions. You can go forward to the next page, or backwards to the previous page, by clicking on the buttons at the bottom of the page.

Please fill in: Your answer will be used only for this project. Thank you for your participation!

First name: ____________________

Family name: ____________________

Organization and department: ____________________

Email address: ____________________

Experience in agricultural research and/or policy (how many years, functions, etc.): ____________________

The questionnaire makes a distinction between three categories of impact factors regarding winter-wheat yield:

1. Direct weather factors
2. Indirect weather factors
3. Management factors

We are interested in understanding which factors are important in Anhui and at which scale level they apply.

The first list shows direct weather factors having an impact on yield. For each factor, please specify:

1. The impact on the yield of winter wheat, in your opinion and experience (first column).
2. The scale of impact: local, regional or both. (Second column)

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Frost damage	❍	❍	❍	❍	❍	❑	❑
High temperature extremes	❍	❍	❍	❍	❍	❑	❑
Drought	❍	❍	❍	❍	❍	❑	❑
Floods/waterlogging	❍	❍	❍	❍	❍	❑	❑
Lodging	❍	❍	❍	❍	❍	❑	❑
Hail	❍	❍	❍	❍	❍	❑	❑

If you know any other direct weather factors that are important for yield variability, please describe them in the text box and specify their impact level and scale level.

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑

This list shows indirect weather factors having an impact on yield. For each factor, please specify: 1. The impact on the yield of winter wheat, in your opinion and experience (first column).

2. The scale of impact: local, regional or both. (second column)

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Diseases (fungal infections caused by high humidity)	❍	❍	❍	❍	❍	❑	❑
Sowing problems with too dry or too wet condition	❍	❍	❍	❍	❍	❑	❑
Harvest losses caused by too much precipitation during harvesting	❍	❍	❍	❍	❍	❑	❑
Insect infestations	❍	❍	❍	❍	❍	❑	❑

If you know any other indirect weather factors that are important for yield variability, please describe them in the text box and specify their impact level and scale level.

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑

The following lists show management factors that influence winter wheat yield. For factors such as fertilizer, irrigation, pesticides and herbicides, both the amount and the timing may impact the yield. Please indicate for the factors below, the impact of their amount on the yield variability between years. For each factor, please specify the scale level as well.

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Fertilizer	❍	❍	❍	❍	❍	❑	❑
Irrigation	❍	❍	❍	❍	❍	❑	❑
control of pests, weeds and diseases	❍	❍	❍	❍	❍	❑	❑

Please indicate for the factors below, the impact of their timing on the yield variability between years. For each factor, please specify scale level as well.

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Fertilizer	❍	❍	❍	❍	❍	❑	❑
Irrigation	❍	❍	❍	❍	❍	❑	❑

The availability of labour and equipment may impact the yield variability between years. Please indicate their impact level and scale level.

	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Labour	❍	❍	❍	❍	❍	❑	❑
Equipment	❍	❍	❍	❍	❍	❑	❑

Do you know any other management factors that may impact winter wheat yield variability between years? If so, please specify them in the text boxes and indicate the impact level and scale level.

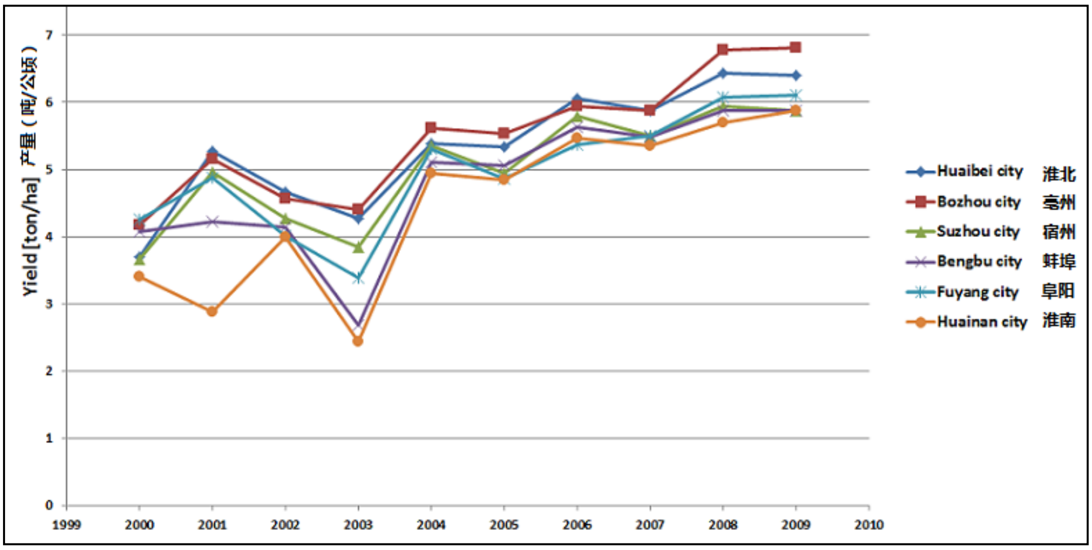
	Impact level					Scale level	
	Hardly any impact 1	Low impact 2	Some impact 3	High impact 4	Very high impact 5	Local impact	Regional impact
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑
Other (please specify and score)	❍	❍	❍	❍	❍	❑	❑

Based on your previous answers, what is the main cause of inter-annual yield variability of winter wheat in Anhui?

- ❍ Weather induced effects.
- ❍ Field management effects
- ❍ Equally important
- ❍ Do not know
- ❍ Caused by others (please specify) ____________________

The following questions relate to the graph below.

Yield of winter-wheat for 6 different districts in the Huaibei plain in Anhui Province (AIFER, 2012)



In 2001, the winter wheat yield decreased in Huainan City, but increased in other cities.

> What was the reason for the decrease in yield in Huainan city according to your knowledge?
>
> And what was the reason for the increase in yield in other cities?

In 2003, the winter wheat yield decreased dramatically in some regions. What was the reason for the decrease in yield according to your knowledge?

From 2004 to 2009, the winter wheat yield shows an increasing trend. What was the reason for that increase in yield in this period according to your knowledge?

Would you like to receive the results of this survey?

- ❍ Yes
- ❍ No

Can we contact you for further information on your answers?

- ❍ Yes
- ❍ No

This was the last question of the survey.

Please press the next button to submit your answers. Thanks!