ABSTRACT. Shaanxi Province in China has been exposed to climate variability and dramatic land-use policies. The aim here is to examine vegetation changes in this area on a regional scale from 2000 to 2004 in relation to land-use changes and climate traits. The data in this assessment include remote sensing information from moderate-resolution imaging spectro-radiometer normalized difference vegetation index from 2000 to 2004, and climate data (precipitation and temperature) from 1956 to 2000. The results show an increase in vegetation production from 2000 to 2004, particularly in the north, which cannot be explained solely by climate impacts. Since the vegetation in the north is more dependent on climate variation than the other parts of Shaanxi due to more serious water limitation, the results suggest that the large-scale land-use policy implemented over the last decade, with a focus on northern Shaanxi, is possibly having an impact on the overall vegetation.

Key words: Loess plateau, NDVI, regional climate

Introduction
The starting point for land-use changes in China can be traced back to the 1978 economic reform that opened up China to the outside world market in a controlled way, a change forced by years of economic stagnation (Lu and Wang 2002). This reform, the Open-Door Policy, allowed China to take part in increased globalization (Yeh and Li 1999; Bao et al. 2002) with expanding trade of agricultural products. The change was further accentuated with the land reform of 1982, the Household Responsibility System, which resolved the communes. As a result, land-use rights were distributed to individual farmers with leases of 15 years. The two reforms have had a clear impact on land use. During the last decade, rising concern about the environmental effects of these reforms and policies has been highlighted (McElroy et al. 1998; Liu et al. 2005), particularly in the area of the Loess Plateau in Shaanxi, which is the focus here (Hu 1997; Liu 1999; Skinner et al. 2001).

In 1999 the Chinese government introduced the Slope Land Conversion Programme at the national level, also known as the Grain for Green Policy (see Feng et al. 2004), and later named the Cropland Conversion Programme at the provincial level in Shaanxi. The massive policy had a budget of over 40 billion US dollars (Xu et al. 2004) and can be seen as one of the most ambitious environmental initiatives globally. The objective was to halt erosion, and indirectly to solve the problem of sedimentation in the big rivers, by encouraging farmers to change crop cultivation on slopes to tree and grass plants. This programme provides compensation to farmers in terms of money and food grains for up to eight years. The targeted land for Shaanxi Province was slopes exceeding 25° and included the planting of locust trees (Robinia pseudoacacia L) mainly (Rui et al. 2001). Shaanxi has converted the most land (0.82 Mha of former agricultural land) of all the 33 provinces or Autonomous Regions covered by the policy. By the end of 2003 this amounted to 7.2 Mha of former cultivated land in the whole of China (Xu et al. 2006), while the total land conversion, i.e. both former agricultural lands and other lands, was 13.3 Mha (Xie et al. 2005). However, earlier studies show that the land-use change situation before the Cropland Conversion Programme was dynamic in Shaanxi (Liu et al. 2005). A total of 44 000 ha of cropland was converted to other land uses while almost 57 000 ha of
new land areas were taken up for crop production from 1990 to 2000, i.e. a net increase of crop area.

In the wake of China’s economic success during the last decade, increasing attention is now being paid to the environmental effects. Land use, agriculture and hence food production are one such area (e.g. Zhao et al. 2005). During the last decades, several large-scale land-use policies have been implemented causing changes in land use and, hence, land cover (Hu 1997; McElroy et al. 1998; Skinner et al. 2001). The latest and largest of these reforms is the Slope Land Conversion Programme. At the same time, climate variability is showing great regional differences. For part of Shaanxi Province there is a decreasing trend in precipitation characterized by erraticism and a significant increase in temperature (e.g. Hageback et al. 2005). Several attempts have been made to evaluate the impact of this policy in terms of economic sustainability (Uchida et al. 2005), livelihood impact (Feng et al. 2004; Xie et al. 2005) or the organization of the programme itself (Xu et al. 2004). However, the impact of this reform on physical land cover in relation to climate variability has not yet been analysed, and is the subject of this study. It has been stressed that to improve the ability to predict land-use change in the near future and its impact on China’s food security and environment, there is a need to investigate the mechanisms that drive land-use change at multiple scales, from landscape to national scales (Liu et al. 2005).

The simultaneous processes of land-use change, seen as a direct human impact, and climate variability, seen as possible indirect human and natural impact, are affecting the overall vegetation. Several studies from northern China have shown links with vegetation status both from land-use policies and climate variability (Runnström 2000; Chen et al. 2005; Fang et al. 2005; Ostwald and Chen 2006). Correlation has been found between the vegetation peak and vegetation index from satellite data and rainfall records in northern China (Runnström 2000). When studying different biomes, increased precipitation gave increased normalized difference vegetation index (NDVI) of grassland and deciduous broadleaf forest, but a decreased NDVI for deciduous coniferous forest. The various biomes also behaved differently depending on precipitation pattern and amount, indicating a non-linear feedback (Fang et al. 2005). More complex and varied relationships between vegetation indices and climate variables were shown in northern Shaanxi when looking at temperature and precipitation in different lagged or pre-seasonal correlations (Ostwald and Chen 2006). It was shown that low temperatures one to three months before August were positively correlated with increasing vegetation production in August, which suggests that reduced evapotranspiration and hence less water stress have a positive effect on vegetation production. Also, a warm spring had a positive effect on vegetation production in August. In general, the vegetation indices showed higher correlation with temperature than precipitation, which indicates that enhanced evaporation due to high temperatures has a negative effect on vegetation growth. Similar results regarding the impact of limiting water supply were shown in a global assessment of sensitivity of NDVI to climate variability (Bounoua et al. 2000). Correlation with temperature rather than precipitation was also determining the start and end dates of growing seasons in temperate China, including Shaanxi (Chen et al. 2005). The temporal scale, or lag, for precipitation and soil moisture increases from humid to dry climates, demonstrates the role of potential evaporation (Entin et al. 2000).

This study investigates relationships among land use, overall vegetation production, and climate variability in Shaanxi Province between 2000 and 2004. How have the vegetation and climate changed over the period? What relationships can be found between vegetation, and possibly land-use changes driven by the policy and climate traits on a regional scale? Are there any regional differences within the province?

Shaanxi Province
Shaanxi Province covers 205 600 km² in northern inland China (31°45’–39°35’N and 105°29’–111°15’E), approximately 2% of the total country. Climate and topography divide the province into three distinct regions: the semi-arid Loess Plateau in the north, the warm-temperate central plain and the sub-tropical region south of the Qinling Mountains (Zhao 1986). These areas have different land uses and are therefore used for the regional analysis in this study (Fig. 1). The main land use in the north is characterized by grassland, rainfed summer crops and sparse woods. Moving to the central area, irrigated croplands, mainly winter wheat and maize, are dominating (Liu et al. 2005). In the south, the main crops are maize, wheat and rice in combination with economic forest, sparse woods, and mixed needle- and deciduous broadleaved
types (Zhao 1986; IIASA 2001). The irrigated area used in agriculture has been fairly constant over the period 2000 to 2004, varying between 1 272 000 and 1 315 000 ha for the whole province (China Agriculture Yearbook 2001–2005). The province is inhabited by 37 million people, with the greatest density in the central, most industrialized part (Knutsson 2005). Approximately 20% of the provincial area is used for agriculture, while half of Shaanxi was considered forested in 2004. The area used for agriculture decreased by 10% from 2000 to 2004, and for forest by 11% from 2003 to 2004 (China Statistical Yearbook 2005). The implementation of forest and grass plantation under the Cropland Conversion Programme is not part of the forest category in these statistics. Between 1980 and 2000 the cultivated land per farmer changed from 0.16 ha to 0.31 ha despite a population increase (Liu and Chen 2005), compared with 0.11 ha as the national average (Liu et al. 2005). Hence, land-use change is in a constant process. Due to its position in terms of monsoon extent and hence limits for rainfed agriculture and the sensitive environment within the Loess Plateau, Shaanxi is representative of northwestern China in terms of climate variability and vegetation changes.

Data and methods

Remote sensing

Moderate-resolution imaging spectroradiometer (MODIS) 13Q1 images were downloaded from EOS data gateway at a spatial resolution of 250 m as 16-day composites, consisting of the highest value for each pixel over a 16-day period. One image for each month from April 2000 (commencement of MODIS data) to December 2004 was collected. There are several characteristics of temporal composited data. They are consistently produced data sets and the cloud contamination is greatly reduced.
The meteorological data were selected to provide a maximum cover for each geographical region in the province. Rather to get overall vegetation changes over different regions, the meteorological data were provided and quality controlled by China Meteorological Administration, Beijing. In addition, information on natural hazards was available for nine agrometeorological stations across the province, provided by Shaanxi Meteorological Bureau, Xi’an.

Impact of climate

Relationships between NDVI on one side, and T, ΣΣ, P and Pfreq on the other, were evaluated over the three different areas (Kang et al. 2002; Fang et al. 2005; Song et al. 2005). Pre-seasonal analysis of the climate parameters in relation to NDVI was computed to identify possible lagging effects as indicated in earlier studies (Ostwald and Chen 2006). This was done over the onset of greening (March–April), and the growing season (April–August), in relation to three different vegetation periods, i.e. start (May–June), peak (July–August) and wilting (September–October) periods and the peak month (August). In testing relationships between climate variables and vegetation through NDVI, mean NDVI rather than maximum NDVI was correlated (Ostwald and Chen 2006) and was therefore used in this analysis. The sum of the accumulated NDVI over different periods was also used, as suggested by Fang et al. (2005). To remove the seasonal cycle, anomalies with respect to the seasonal means were used. Statistical significance tests were performed using one-tailed Pearson’s test (Ebdon 1985).

Result and discussion

Climate variability and change

Climate change and variability have significant effects on land use, including agriculture and forestry. In China, agriculture is strongly dependent on climate and is thus susceptible to climate change (Smit and Cai 1996). These changes occur both on a large scale related to, for example, the East Asian monsoon system (Tao et al. 2004; Gordon et al. 2004; Li et al. 2004; Fang et al. 2005; Song et al. 2005).
2005) and on a regional scale related to human impact, such as increased emissions of absorbing black carbon (Menon et al. 2002). In Shaanxi Province, regional and local climates have shown a change over the last 50 years (Hageback et al. 2005; Ostwald et al. 2004). For example, Hageback et al. (2005) showed an increase in annual mean temperature of 0.9°C in Ansai (northern Shaanxi) for the period 1955–2004. Furthermore, our data show that the number of days with daily mean temperature above 0 and 5°C increased by around 20 and 15 days respectively in 40 years (1956–2004), indicating a longer potential growing season.

Precipitation generally has a great variability and 40–70% falls between May and September. The total annual amount has a clear decadal variation and the linear trends are relatively weak (Song et al. 2005; Zhao et al. 2005). The most significant seasonal trends occurred during spring (March–May) and winter (December–February) for both mean temperature and for precipitation (Table 1). The winter precipitation in the north increased significantly, by 20 mm in 49 years, and decreased in the other seasons. The precipitation decreased by 38.2 mm in 49 years, with the greatest decrease in the central region. The annual mean temperature over the whole province increased by 1°C from 1956 to 2004.

Over the five years considered in this study, mean monthly total precipitation and mean temperature show a cooler and drier northern region, a warmer central region and a warmer and wetter southern region (Fig. 2). When looking at the differences over time, the year 2000 was dry especially in the north, while 2004 was wet (Fig. 3). Agrometeorological stations throughout the province recorded droughts, particularly in 2000 and 2002, and the northernmost stations reported droughts in all five years. However, the natural hazard data bear no relation to the total annual precipitation since serious droughts have also been reported for years with normal or above-normal rainfall amount. The annual precipitation in the five years starting from 2000 were 441, 588, 549, 682, 422 mm in the north 538, 432, 444, 911, 531 mm in the central region, and 856, 628, 629, 975, 713 mm in the south, respectively. The annual mean temperatures were 11.6, 11.9, 12.2, 11.7, 11.8°C in the north, 15.8, 15.9, 16.5, 15.7, 15.9°C in the central region, and 16.7, 16.7, 17.3, 16.7, 16.7°C in the south, respectively.

Over the five-year period (Fig. 3) the relative differences in climate were as follows.

- **2000**: Spring generally dry, especially in the north and south, and also warm in the south. Summer dry in the north and wet in the south. Winter warm and wet in the north.
- **2001**: Spring generally dry, especially in the central region. Summer warm in the north, dry in the central region. Autumn dry in the south. Winter generally warm, especially in the north and the central region.
- **2002**: Spring generally wet. Summer generally warm and dry, especially in the central region and the south. Autumn generally warm and dry, especially in the central region and the south. Winter generally wet; cold especially in the north and the central region.
- **2003**: Spring generally cold; wet in the central region. Summer generally cold; wet in the north and the central region while quite dry in the south. Autumn generally wet; cold in the south. Winter generally dry, especially in the north and the central region; warm in the central region.
Table 1. Mean, variability and linear trends of monthly temperature and precipitation during 1956–2004 on an annual and seasonal basis

<table>
<thead>
<tr>
<th></th>
<th>Shaanxi</th>
<th></th>
<th></th>
<th></th>
<th>North</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yearly</td>
<td>Spring</td>
<td>Summer</td>
<td>Autumn</td>
<td>Winter</td>
<td>Yearly</td>
<td>Spring</td>
<td>Summer</td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>17.8</td>
<td>19.2</td>
<td>29.8</td>
<td>17.5</td>
<td>4.7</td>
<td>16.1</td>
<td>17.8</td>
<td>26.1</td>
</tr>
<tr>
<td>Std of temperature (°C)</td>
<td>0.7</td>
<td>1.0</td>
<td>0.9</td>
<td>1.0</td>
<td>1.4</td>
<td>0.8</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Linear trend (°C/yr or season)</td>
<td>0.02**</td>
<td>0.02**</td>
<td>0.00</td>
<td>0.02*</td>
<td>0.04**</td>
<td>0.03**</td>
<td>0.02*</td>
<td>0.01</td>
</tr>
<tr>
<td>Total change calculated from the trend (°C/49 yrs)</td>
<td>1.0</td>
<td>1.2</td>
<td>0.1</td>
<td>1.0</td>
<td>1.9</td>
<td>1.3</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Mean precipitation (mm)</td>
<td>558.2</td>
<td>110.6</td>
<td>286.6</td>
<td>151.3</td>
<td>9.7</td>
<td>494.7</td>
<td>82.1</td>
<td>287.4</td>
</tr>
<tr>
<td>Std of precipitation (mm)</td>
<td>92.3</td>
<td>36.2</td>
<td>63.1</td>
<td>54.2</td>
<td>9.0</td>
<td>102.9</td>
<td>40.4</td>
<td>74.2</td>
</tr>
<tr>
<td>Linear trend (mm/yr or season)</td>
<td>-0.8</td>
<td>-0.4</td>
<td>-0.4</td>
<td>0.4**</td>
<td></td>
<td>-0.5</td>
<td>0.1</td>
<td>-0.7</td>
</tr>
<tr>
<td>Total change calculated from the trend (mm/49 yrs)</td>
<td>-38.2</td>
<td>-18.3</td>
<td>-20.7</td>
<td>-20.6</td>
<td>20.1</td>
<td>-22.7</td>
<td>6.2</td>
<td>-34.7</td>
</tr>
<tr>
<td>Total change calculated from the trend (%/49 yrs)</td>
<td>-7.1</td>
<td>-18.0</td>
<td>-7.5</td>
<td>-14.7</td>
<td>100.6</td>
<td>-4.7</td>
<td>7.2</td>
<td>-12.9</td>
</tr>
<tr>
<td></td>
<td>Central</td>
<td></td>
<td></td>
<td></td>
<td>South</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>19.1</td>
<td>20.1</td>
<td>31.0</td>
<td>18.7</td>
<td>6.5</td>
<td>18.2</td>
<td>19.6</td>
<td>30.2</td>
</tr>
<tr>
<td>Std of temperature (°C)</td>
<td>0.8</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.4</td>
<td>0.7</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Linear trend (°C/yr or season)</td>
<td>0.02**</td>
<td>0.03**</td>
<td>0.00</td>
<td>0.02*</td>
<td>0.03**</td>
<td>0.02**</td>
<td>0.02*</td>
<td>-0.01</td>
</tr>
<tr>
<td>Total change calculated from the trend (°C/49 yrs)</td>
<td>1.1</td>
<td>1.4</td>
<td>0.2</td>
<td>1.0</td>
<td>1.6</td>
<td>0.8</td>
<td>0.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>Mean precipitation (mm)</td>
<td>588.1</td>
<td>127.5</td>
<td>270.8</td>
<td>178.4</td>
<td>11.4</td>
<td>591.4</td>
<td>122.1</td>
<td>301.5</td>
</tr>
<tr>
<td>% of yearly total</td>
<td>22</td>
<td>46</td>
<td>30</td>
<td>2</td>
<td>0.00</td>
<td>21</td>
<td>51</td>
<td>26</td>
</tr>
<tr>
<td>Std of precipitation (mm)</td>
<td>127.9</td>
<td>47.2</td>
<td>91.9</td>
<td>75.9</td>
<td>12.3</td>
<td>94.3</td>
<td>32.8</td>
<td>71.9</td>
</tr>
<tr>
<td>Linear trend (mm/yr or season)</td>
<td>-1.7</td>
<td>-0.7</td>
<td>-1.2</td>
<td>-0.4</td>
<td>-0.6**</td>
<td>-0.2</td>
<td>-0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Total change calculated from the trend (mm/49 yrs)</td>
<td>-82.9</td>
<td>-34.7</td>
<td>-58.1</td>
<td>-18.3</td>
<td>26.8</td>
<td>-8.9</td>
<td>-26.2</td>
<td>30.8</td>
</tr>
<tr>
<td>Total change calculated from the trend (%/49 yrs)</td>
<td>-15.2</td>
<td>-31.6</td>
<td>-24.1</td>
<td>-10.8</td>
<td>106.9</td>
<td>-1.5</td>
<td>-24.1</td>
<td>9.7</td>
</tr>
</tbody>
</table>

Pearson’s correlation coefficients were tested (one-tailed) with Pearson’s test for significance using SPSS. Significance level: **0.01, *0.05
Fig. 3. Anomalies of monthly mean NDVI, mean temperature (*10°C) and total precipitation (mm) for 2000–2004 in (a) north, (b) central, and (c) south region.

**0.01 level one-tailed Pearson’s test. T, P and NDVI central showed no significant trend.**

NDVI: $y=7.0x-239, R^2 = 0.15^{**}$
2004 Spring generally warm, especially the north and the central region; dry in the north. Summer generally quite cold. Autumn dry.

Vegetation analysis
The provincial mean NDVI shows a vegetation change over the period with 2002 and 2004 indicating an earlier spring (Fig. 4). There is also an increase in the peak month, August, for 2004. The last three years (2002 to 2004) point to a higher activity of chlorophyll during June to October than in the earlier years. Furthermore, 2003 indicates a productive autumn period compared to the other years. Three of the five years (2000, 2003, 2004) have a diminishing production in June giving the profile a bimodal character, which could indicate more than one distinguished land cover type present in the signature. The multi-temporal profile suggests a growing season from April to November.

The NDVI patterns differ when dividing the data into the three regions (Fig. 5). The north has the lowest NDVI value while the south has the highest. The difference between the years is greatest in the north where NDVI increased during the last three years (2002 to 2004). This increase could be due to the Cropland Conversion Programme effect since the north is characterized by slopes, the landform that is the focus for the programme. The south shows a comparatively smoother growing season and little change between years. The central part shows a bimodal pattern signifying a harvest in May/June.

The percentage of the land area that has experienced an increase in vegetation activity in the peak month (August) from 2000 to 2004 is 79%, 52% and 51% for the north, central region and south, respectively. The increasing vegetation trend is significant particularly in the north ($R^2 = 0.42$) but also in the south ($R^2 = 0.15$) based on the anomalies of monthly mean of the whole period (Fig. 3a and c).

Over the five-year period (Fig. 5) the relative differences in the NDVI were as follows.

2000 Early spring in the south. Low productivity in June for the central region. Low productivity in general, particularly in the north.
2001 Productivity peak in September in the central region. Higher productivity in June in the central region compared to all other years. Low productivity dip in July in the central region.
2002 Earlier spring in the south than in previous years. Highest productivity in June of all the years in the north. Lowest productivity of all the years from September to November in the central region.
2003 High productivity in autumn in the north and the south. 2004. Highest productivity in April and August of all the years in the north. Early spring in the south.

Correlation between climate and vegetation in the three regions
To determine the relationships between vegetation and climate parameters we will take a closer look at each region, from north to south, and finish with a synthesis. We start with some particular NDVI values or patterns and link these to the climate data.

As seen in Fig. 5, the southern part of Shaanxi
Fig. 5. Mean NDVI values and standard deviation from April 2000 to December 2004 over the three regions of Shaanxi Province with percentage of area with vegetation change from August 2000 to August 2004. (a) North, (b) Central, and (c) South region. Start of growing period (May–June), peak growing activity (July–August) and wilting period (September–October) are indicated. NDVI values are given (× 10^4).
has changed very little over the five-year period in terms of NDVI, while the climate variables in Fig. 3 show a great interannual variability. A similar climate pattern can be observed in the central part, especially in terms of temperature. Corresponding similarities between the south and central region are not found in the vegetation pattern. The area with increased vegetation from 2000 to 2004 is also lower in the south (51%) and central region (52%) than in the north (79%). This implies that climate is not the only factor driving the vegetation change. Increased vegetation provides more transpiration (latent heat) which in turn has a cooling effect that can be seen in all the regions for the five-year period (Fig. 3), especially the north. This would suggest that there is a feedback between the vegetation and the local and regional climates.

In the northern region, agriculture consists mainly of one summer crop (planted in April to June and harvested in August or September) with or without a winter crop. The harvest effect is seen in the dip of the NDVI anomalies between June and July (Fig. 3). However, the harvest cannot be detected as absolute NDVI since it constitutes a relatively small area in the north as a whole (Fig. 5). Between 2000 and 2004 we see steadily increasing NDVI values in the peak period which are not evident in the other two regions, particularly the southern region (Fig. 3). Furthermore, this NDVI value is not only related to rain patterns, as 2004 was comparatively dry, both in amounts and frequency. This could instead be the influence of the tree planting policy, which primarily should be taking place in the north since the Cropland Conversion Programme was aimed at slope land which is abundant in the Loess Plateau in the north. Newly planted Locust trees may grow 0.5–3 m per year with a rapid canopy increase (Singh 1982).

In the central region the dip in the June NDVI values reflects agricultural harvests of spring crop (May–June) and summer crop (September–October) (Fig. 5). Furthermore, although precipitation is significantly correlated with NDVI simultaneously (Table 2), the NDVI values are obscured by irrigation, e.g. 2003 (cold spring, wet summer) and 2004 (warm spring, dry summer) both produced high NDVI values in August (Figs 5 and 3). Seasonal NDVI development in 2001 is exceptional; higher values than any other year in May, and then lower between July and August, ascending to average in September. This is most likely related to low precipitation amounts from March to June; this could entail a delayed harvest, which appears as low July NDVI. For the agrometeorological data there is no evidence for a lower yield or later than normal harvest in terms of winter wheat in 2001; on the other hand, droughts were frequent. Again, the effect of irrigation is shown.

The mean monthly temperatures in the central region and the south are generally above +5°C, which allows for a long growing season, as monitored by the NDVI. For the central region it is possible to see a combination of temperature and precipitation (Table 3), in that temperature initiates the NDVI in the start period, and then precipitation takes over NDVI during the peak. In both 2001 and 2002 the central region has a high NDVI value at the beginning of the year, but not particularly high values in August, compared to 2003 and 2004 which have low NDVI values at the beginning of the year but high values around August. The summer temperatures for these two groups are higher in 2001 and 2002 than in 2003 and 2004. Apart from weather variability, the high temperatures may be due to (i) either an increase in evaporation to the extent that not even irrigation can compensate the loss, or (ii) the plants, mostly maize, are experiencing moisture stresses leaving them with lower chlorophyll, i.e. lower NDVI.

The southern region NDVI has a smoother annual profile in general and a two to three month peak,
which probably reflects the sub-tropical influence, regardless of summer bi- or trimodal precipitation distribution. Interestingly there is no NDVI decrease corresponding to the ‘harvest effect’ seen in the north and central region. The dip between May and June 2000 is probably not a harvest effect but rather an effect of the heavy rainfall during June (211 mm) flooding the paddy fields and leaving little greenness.

Pre-seasonal climate effects on vegetation in the three regions

To evaluate the impact of climate variability on vegetation, seasonal cycles were removed by using monthly anomalies. Further, correlation analysis was conducted using simultaneous and lagged data sets (Table 2) for the whole time period.

Contrary to the previous findings in this part of China by Chen et al. (2005) and Ostwald and Chen (2006) and similarly to Runnström (2000), there is a stronger correlation between precipitation and NDVI than between temperature and NDVI. One explanation is the water dependency. At the regional level water stress is more pronounced in the arid north compared to the greatly irrigated central part and the sub-tropical south. The negative correlations (both significant and non-significant) during April to August in the north between NDVI and temperature indicate that during warm periods there is a higher evaporation and water stress causing less vegetation. In the central region, NDVI is well correlated with precipitation from the same month, hence grain crop biomass growth reacts directly to rainfall as seen by Kang et al. (2002), while lagged precipitation has little effect due to irrigation. In the north, precipitation and NDVI correlate in all temporal lags except the simultaneous precipitation, confirming that stored soil water is crucial for vegetation, as suggested by Entin et al. (2000) and Fang et al. (2005). In the south, on the other hand, water is not limiting growth. Temperature correlates significantly with NDVI in only one case, i.e one year lag in the south (Table 2).

For mean temperature (T), temperature sum (TΣ), precipitation (P) and precipitation frequency (Pfreq) during the periods March–April and April to August, few correlations were found with the sum of accumulated NDVI for the different vegetation periods (Table 3). Furthermore, correlations were generally highest for the growing

Table 3. Correlation coefficients between sums/means of temperature and precipitation over various periods including climate data from 1999 to 2004 and NDVI data from 2000 to 2004.

<table>
<thead>
<tr>
<th>NDVI</th>
<th>March–April</th>
<th>April–August</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T mean</td>
<td>T Σ&gt;0</td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
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<td>0.56</td>
</tr>
<tr>
<td>Start period 2</td>
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</tr>
<tr>
<td>Peak period 3</td>
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</tr>
<tr>
<td>Wilting period 4</td>
<td>-0.04</td>
<td>-0.01</td>
</tr>
<tr>
<td>August</td>
<td>0.79</td>
<td>0.82*</td>
</tr>
<tr>
<td>Central</td>
<td></td>
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<tr>
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<td>0.12</td>
</tr>
<tr>
<td>Start period 2</td>
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</tr>
<tr>
<td>Wilting period 4</td>
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<td>-0.47</td>
</tr>
<tr>
<td>August</td>
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<td>0.12</td>
</tr>
<tr>
<td>South</td>
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<tr>
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<tr>
<td>Start period 2</td>
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</tr>
<tr>
<td>August</td>
<td>0.21</td>
<td>0.20</td>
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</table>

1 The growing period = April–Aug
2 The start period = May–June
3 The peak period = July–August
4 The wilting period = September–October. Significance level of 0.05 is indicated by * with one-tailed Pearson’s test
season period (April to August). Mean T and TΣ gave greater differences in correlation in the north than in the other regions. Low temperature during April to August in the north is correlated with the accumulated NDVI during the start of the growing period (May–June) and during the wilting period (September–October), again indicating that a water stress situation is soothed by less evapotranspiration. The peak vegetation period is not affected by evaporation to the same extent since this is the wettest period. On the other hand, Pfreq in the north is more important for vegetation than P amount. This suggests that frequent rainfall makes more water available for plants, hence increasing NDVI in the north. In rain storms, however, water is lost quickly as runoff rather than transpiration. This is not seen in the south and the central region. Both the central region and particularly the south show that for a high peak NDVI, the P amount is comparatively more important than both Pfreq and temperatures, especially at the start and peak vegetation.

Even if there are few statistically significant correlations between the NDVI and climate variables, notable patterns emerge. If we compare the different regions it is remarkable that the north and also the south have higher correlations with the different climate variables than the central parts. This can be an indication that irrigation is playing a central role for agriculture in the central region, which is not surprising since this is where most of the irrigation is found. There is no pattern of trend in terms of irrigated land area for the province during 2000 to 2004 (China Agriculture Yearbook 2001–2005); in fact the irrigated area has remained within the same range over the last 25 years (Deng et al. 2005). The central region has more easily available irrigation water because of its topography; it also has more flatlands which allows for more intensive agriculture compared to the two other regions, which are characterized by rainfed agriculture in the north and sub-tropical paddy-dominated farming in the south.

To increase the understanding of relation between vegetation change, climate variability and land-use policy, the future is promising with regard to longer time series of data, which has been a limitation to this study. Of particular interest is the impact of the termination of the subsidies to farmers in 2008, which has been a central part of the design of the land-use policy. Further, with the eventual increase in vegetation in the province, the coupling between climate variables and vegetation will be one important research area in the years to come.

Conclusions

– The climatic trend in Shaanxi between 1956 and 2004 can be summarized as a significant increase in seasonal mean temperature accompanied by decreasing precipitation in three of the seasons.
– Vegetation production, expressed as anomalies of NDVI, has increased in Shaanxi from 2000 to 2004. Despite variability, the trend is statistically significant in the north (R² = 0.43, p < 0.01) and the south (R² = 0.15, p < 0.01).
– Pre-seasonal analysis based on monthly anomalies of climate and NDVI data over the whole year gave significant correlations mainly with precipitation in the north, indicating the importance of water supply in that region.
– The north shows a general temperature decrease from 2000 to 2004 in July, the hottest month. Further, correlation analysis indicates that vegetation is more closely coupled to climate in the north as compared to the other two regions.
– The general vegetation increase (79% in the north), where more slope land has been converted than in the central and the southern regions, suggests an impact of the Cropland Conversion Programme in addition to climate change.

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Note

* North: Yulin (109°42'E, 38°14'N), Yan’an (109°30'E, 36°36'N), Luochuan (109°30'E, 35°49'N). Central: Baoji (107°13'E, 34°35'N), Xi’an (108°33'E, 34°30'N). South: Shangzhou (109°58'E, 33°52'N), Hanzhong (107°03'E, 33°07'N), Ankang (109°02'E, 32°43'N).

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