The Rediscovery of Intercropping in China: A Traditional Cropping System for Future Chinese Agriculture – A Review

Heike Knörzer, Simone Graeff-Hönninger, Buqing Guo, Pu Wang, and Wilhelm Claupein

Abstract Intercropping has a 1000-year old history in Chinese agriculture and is still widespread in modern Chinese agriculture. Nowadays, agricultural systems in China are stigmatized to exhaust high levels of input factors like N fertilizer or irrigation water and to contribute severely to environmental problems like desertification, river eutrophication, soil degradation and greenhouse effect. In this context, monocropping systems have to be revised and may not be the best performing systems any more, considering sustainability, income security and nutritional diversity in rural areas. Therefore, intercropping systems offer alternatives for a more sustainable agriculture with reduced input and stabilized yield. Especially in the last decade this cropping system has been rediscovered by scientific research. Studies showed increased yield of maize and wheat intercropped with legumes: chickpea facilitates P uptake by associated wheat, maize intercropped with peanut improves iron nutrition and faba bean enhances N uptake when intercropped with maize. China's intercropping area is the largest in the world. Nevertheless, there are only few international studies dealing with intercropping distribution, patterns and crops. Most studies deal with nutrient-use efficiency and availability. This study is a first approach to gain an overview of intercropping history, basic factors about interspecific facilitation and competition and distribution of Chinese intercropping systems. Finally, four intercropping regions can be distinguished and are explicitly described with their intercropping intensity, potential and conditions.

Keywords Arable crops · China · Intercropping · Sustainable agriculture

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1 Introduction

It may be referred to as an ancient and traditional cropping system, but has a serious potential to contribute to a modern and sustainable agriculture in China. Intercropping, defined as a kind of multiple cropping system with two or more crops grown simultaneously in alternate rows in the same area (Federer, 1993) while minimizing competition, is practiced in China for thousands of years. In general, intercropping can be done with field, vegetables and even tree crops. Available growth resources, such as light, water and nutrients are more completely absorbed and converted to crop biomass by the intercrop as a result of differences in competitive ability for growth factors between intercrop components. The more efficient utilization of growth resources may lead to yield advantages and increased stability compared to sole cropping and, hence, offers an option for a sustainable low-input cropping system and economic benefits. Though this practice may have some drawbacks, some may be overcome by proper intercrop selection and management. Table 1 lists possible benefits and uncertainties of intercropping compared to classical monocropping systems.

In China, estimations between more than 28 million ha (Li et al., 2007) and 3.4×10^7 ha (Li, 2001) of annually sown area are under intercropping, with a big share in agroforestry (Table 2).

Table 1 Benefits and uncertainties of intercropping systems

Benefits	Uncertainties
Maximized land use	Limited possibilities for production mechanization
Allows more than one harvest per year (e.g. with relay intercropping)	Harvesting produce more difficult
Diversification of crops for market supply	Higher management demand
Risks of crop failure may be reduced	No extensive production of stable or cash crops
Farmers may be better able to cope with price variability	A poorly chosen intercrop competes with main crop
Higher yield and improved resource efficiency	Intercropping may not significantly improve the soil nitrogen levels
Boost the soil nitrogen content in the medium-to-long term especially when legumes are involved	Herbicide use may be constrained
Soil structure may improve if plants with various root structures are grown	
Rotation effect and improving soil erosion control	
Reducing pests and weeds	
Reducing reliance on energy-intensive farming inputs and therefore less eutrophication and emission	

Table 2 Average farm size, intercropping practice and arable land in Africa, China and India*

Country	Farm size (ha)	Intercropping area	Intercropped species	Arable land (million ha) (of total land)	Population (million)
Africa	2	83% of all cropped land in Northern Nigeria; 94% in Malawi	Cowpea, cassava, plantain, yam, rice, sorghum, millet, maize, sweet potato, okra, cocoa, soybean, chickpea, pigeon pea, peanut, beans	182.3 (6%)	812.6
China	0.1	20–25% of arable land	Maize, soybean, peanut, potato, wheat, millet, faba bean tobacco, cotton, sorghum, sesame, garlic, vegetables, cassava	137.1 (16%)	1,320.9
India	1.2–2.7	17% of arable land	Peanut, pigeon pea, maize, soybean, sugarcane, jatropha, rubber, cabbage, coconut, banana, cassava, sorghum, rice, mustard, amaranth, potato, wheat	160.6 (57%)	1,081.3

*Source: American Society of Agronomy (1976); Beets (1982); Cohen (1988); FAO (2004); Li (2001); Li et al. (2007); Vandermeer (1989); Wubs et al. (2005).

Not only tradition and extent of intercropping practice in China are liable for the appearance of a great number of studies dealing with intercropping in China, but the alternatives and options of this cropping system for ecological and sustainable agriculture, especially over the last decade. Foremost in the last decade, Chinese researchers showed an increasing interest in this cropping system. However, research on intercropping has mostly been carried out in Africa, India and Australia, leading to a better understanding of these systems in these countries.

Internationally published studies dealing with intercropping convey the impression that the main interest of these systems lies upon plant nutrition as most of them consider the increased nutrient availability and uptake, the soil nitrate content and N leaching under intercropping in comparison with monocropping (Table 3). However, there is still a research gap considering crop production and cropping designs, especially as the studies about nutrient supply and availability in intercropping systems are mostly conducted under controlled conditions. The performance and behavior of intercropping systems in comparison to monocropping systems under field conditions are still fairly unknown. In addition, other aspects like N-efficiency, water-use efficiency, influence of tillage, pests and diseases or even the calculation of land equivalent ratios (LERs) have not been considered in the international literature so far. Further, in contrast to other countries like India or Africa, in China there is no special breeding of varieties suitable for intercropping comparable to a few approaches in some African regions. In rural areas, intercropping is practiced as a so-called unconscious cropping system, which forms a big part of the whole intercropping area in China: monocropped fields that are enclosed with one row of a different crop to separate them from neighbouring fields, limited field size turning the borderlines of one field to another to an intercropping pattern (Fig. 5). Of course, intercropping is common and widespread, but the main reason for a farmer to carry out intercropping is to use all available land for production, as arable land is scarce. Due to restricted land-use rights Chinese farmers are not able to increase the size of their farms and expand cropping areas. Hence, maximizing yields is only possible by optimizing crop management strategies leading to a better utilization of natural resources over space and time. Intercropping may be a suitable strategy to do so as multiple crops can be grown simultaneously over space and time offering the chance to better utilize solar radiation, nutrients and water over the growing period. Intercropping bears more advantages and is more than maximized field exploitation.

In China, two main systems of intercropping are common: strip intercropping and relay intercropping (Fig. 1, 3). Strip intercropping is defined as cropping two or more crops simultaneously in different strips, wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically (Vandermeer, 1989). Relay intercropping means the maturing annual crop is interplanted with seedlings or seeds of the following crop (Federer, 1993). Intercropping can be practiced further as an additive or a replacement system (Fig. 2). Additive means that one crop is planted in a similar arrangement to its sole-crop equivalent, and a second crop is added, so that the total plant density increases (Keating and Carberry, 1993). In contrast, a number of a few rows of one crop can be replaced by a second crop with total plant density not necessarily changing.

Table 3 Overview over experiments and main researches dealing with intercropping cereals in China

System	Main research	References
wheat/maize	Spatial compatibility and temporal differentiation of root distribution	Li and Zhang (2006); Li et al. (2006);
	Competition-recovery production principle	Li et al. (2001b); Zhang and Li (2003).
	NO_3^- content in the soil profile or NO_3^- concentration in the rhizosphere or N uptake	Li et al. (2005); Song et al. (2007); Ye et al. (2005); Zhang and Li (2003).
	Inner- and border-row effects	Li et al. (2001).
wheat/soybean	N_2 fixation rate and/or N uptake	Li and Zhang (2006); Li et al. (2001b); Zhang and Li (2003).
	Competition-recovery production principle	Li et al. (2001b).
	Inner- and border-row effects	Li et al. (2001a).
wheat/faba bean or maize/faba bean or wheat/chickpea or maize/chickpea	Utilization, availability and uptake of P	Li and Zhang (2006); Li et al. (2003); Li et al. (2004); Li et al. (2004); Li et al. (2007); Zhang and Li (2003); Zhang et al. (2004).
	Utilization, availability and uptake of N	Li et al. (2003); Song et al. (2007); Xiao et al. (2004); Yu and Li (2007); Zhang et al. (2004).
	NO_3^- content in the soil profile	Li et al. (2005).
	Spatial compatibility and temporal differentiation of root distribution	Li et al. (2006).
maize/peanut	Reduction of Fe chlorosis	Inal et al. (2007); Zhang and Li (2003); Zhang et al. (2004); Zheng et al. (2003); Zuo et al. (2004).
	N_2 fixation rate and/or N uptake	Zuo et al. (2004).
	Nutrient (Fe, P, N, K, Ca, Zn, Mn) supply	Inal et al. (2007).

Two practical examples, first for strip or row intercropping, second for relay intercropping, should be mentioned which show the positive implications of intercropping. First, in China's northeast 0.3×10^6 ha of maize fields have been converted to intercropping with sweetclover. Even by planting one-third of the field with

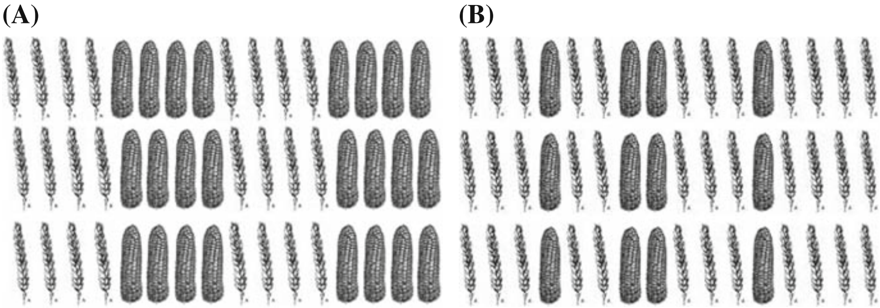

Fig. 1 Scheme of the two main intercropping systems in China: Strip intercropping (**A**), where two or more crops are grown simultaneously on the same field in different strips, e.g. four rows of crop A and four crops of crop B. Relay intercropping (**B**), where the maturing annual plant is interplanted with seeds of the following crop, e.g. 75% of wheat is sown in autumn and a few days or weeks before wheat harvest, maize is interplanted

sweetclover, the results in maize yields are about the same as those from monoculture. But there are additional 15 t/ha of sweetclover to feed three cows a year (Wen et al., 1992). Thus,without maize yield reduction, the amount and quality of pasture can be improved leading to an extension or an increase in livestock, as livestock farming is often based upon substrate fodder. Especially around the big cities Beijing, Tianjin and Shanghai and in the provinces Jiangsu, Zhejing and Fujian, cattle are mostly used for unimproved production and draught (Guohua and Peel, 1991). Improved production for milking is necessary to increase in nearly all provinces, and therefore, good and enough pasture is a big point. Second, relay intercropping showed that it is possible to increase grain yields of summer maize without a

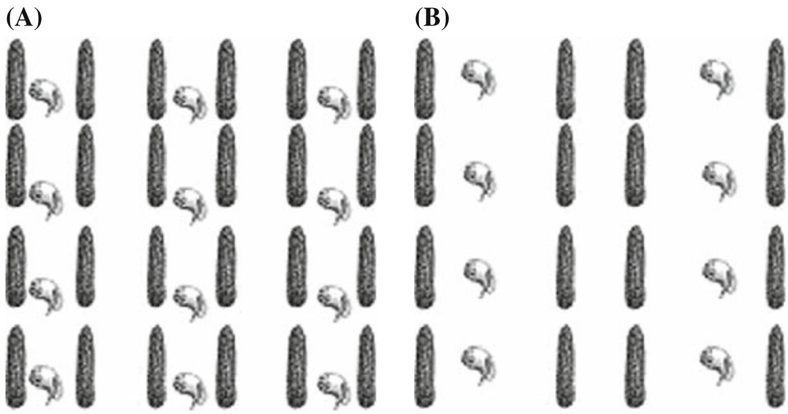

Fig. 2 Considering plant density, two main systems of intercropping exist. (**A**) In an additive intercropping system (l.), crop A is planted in a similar arrangement and amount to its sole-cropped equivalent, and a crop B is added. Total plant density increases. (**B**) In a replacement system (r.), a few rows of crop A are replaced by crop B. Total plant density does not necessarily change

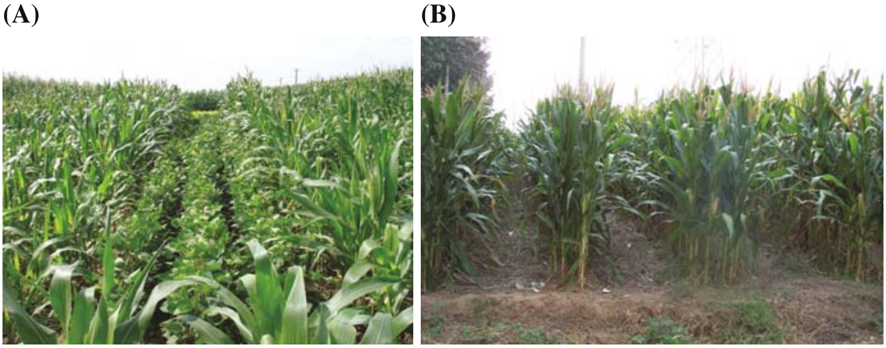

Fig. 3 Two examples of typical intercropping systems in the North China Plain: (**A**) Strip intercropping of maize and soybean (l.), where two or more crops are grown simultaneously on the same field in different strips. Three rows of soybean alternate with maize. These small strips often mark the borderline between two fields owned by different farmers and are the so-called unconscious intercropping. (**B**) Relay intercropping of wheat and maize, where the maturing annual plant is interplanted with seeds of the following crop (r.). Wheat and maize have a few days or weeks of overlapping growing season. When the wheat is harvested, the maize still grows for more than 3 months. In such a system plant density of maize is less than in monocropped systems (pictures: Zhang, F. and Feike, T.)

decrease in winter wheat productivity. This is remarkable, since only 75% of winter wheat sowing acreage is cultivated (Böning-Zilkens, 2004). But there is additional summer maize yield because of an elongated growing season.

2 General Questions About Competition and Facilitation

A brief basic introduction on intercropping, the influencing factors like competition for radiation, CO_2, water and nutrient availability, the ratio of competition and facilitation, resource capture and conversion efficiency is given by Vandermeer (1989) and Fukai and Trenbath (1993). Previous studies mainly dealt with competition (Keating and Carberry, 1993; Tsubo et al., 2001) and less with facilitation. However, interspecific competition and facilitation are two aspects of the same interaction, turning the system of intercropping to a successful one under some circumstances. Jolliffe (1997) pointed out that mixtures are significantly more productive than pure stands on an average of 12%. Current studies pronounce the interspecific facilitation (Li et al., 2001a,b, 2007; Zhang and Li, 2003) and hence, cultures or cereals suiting to each other for a better cropping management. Factors like root distribution (Li et al., 2006), root interactions (Inal et al., 2007; Li et al., 2003b; Zhang et al., 2004; Zheng et al., 2003), above- and below-ground interactions meaning row effects (Li et al., 2001a; Zhang and Li, 2003), N, P, K (Li and Zhang, 2006; Li et al., 2003b, 2004, 2007) and Fe (Zheng et al., 2003; Zuo et al., 2004) supply or modeling competition (Bauer, 2002; Kiniry et al., 1992; Piepho, 1995; Rossiter and Riha, 1999; Yokozawa and Hara, 1992) have been studied recently.

Competition or facilitation extents are difficult to class with their overall extent because of their intermingling. The success of intercropping is attempted to be measured by calculating the relative performance of the species. The most common parameter for judging the effect of intercropping is the land equivalent ratio (LER). A long, detailed and comprehensive list of international studies using the LER as an indicator of success is shown by Innis (1997). There, in almost all studies, LER was greater than 1 indicating that the intercropped species overyielded its monocropped counterparts. The LER is defined as

$$\mathrm{LER} = \sum_{\mathrm{j=1}}^{\mathrm{n}} Y_{\mathrm{ji}}/Y_{\mathrm{js}} \qquad \text{(Wubs et al., 2005).}$$

Y_{ji} = yield of component crop *j* in intercropping
Y_{js} = yield of component crop *j* in sole cropping

Jolliffe (1997) promoted the relative yield ratio (RYT) instead of the LER, but the RYT may be equivalent to LER as the same formula is used:

$$\mathrm{RYT} = \left[(Y_{\mathrm{i}})_{\mathrm{m}} \,/\, (Y_{\mathrm{i}})_{\mathrm{m}}\right] + \left[\left(Y_{\mathrm{j}}\right)_{\mathrm{m}} \,/\, \left(Y_{\mathrm{j}}\right)_{\mathrm{m}}\right] \qquad \text{(Jolliffe,1997).}$$

Y = yield
i, j = species 1 and 2
m = species mixture
p = pure stand

RYT and LER do not express the simple ratio of mixture to pure stands, nor do they involve equal populations and areas allocated to mixture and pure stands (Jolliffe, 1997). Instead, Jolliffe calculated the relative land output (RLO):

$$\mathrm{RLO} = \left(Y_{\mathrm{i}} + Y_{\mathrm{j}} + \ldots\right)_{\mathrm{m}} \,/\, \left(Y_{\mathrm{i}} + Y_{\mathrm{j}} + \ldots\right)_{\mathrm{p}} \qquad \text{(Jolliffe,1997).}$$

In order to get some information about the competitive ability of one species to another, the aggressivity (*A*) can be calculated:

$$A_{\mathrm{ab}} = \left[Y_{\mathrm{ia}}/\,(Y_{\mathrm{sa}} * F_{\mathrm{a}})\right] - \left[Y_{\mathrm{ib}}/\,(Y_{\mathrm{sb}} * F_{\mathrm{b}})\right] \qquad \text{(Li et al., 2001a).}$$

Y = yield
s = sole cropping
i = intercropping
F = proportion of the area occupied by the crops in intercropping
a, b = crop 1 and 2

When $A_{\mathrm{ab}} > 0$, the competitive ability of crop A exceeds that of crop B. In addition, the nutrient competitive ratio (CR) is given in the following equation:

$$CR_{ab} = \left[NU_{ia} / (NU_{sa} * F_a)\right] / [NU_{ib} (NU_{sa} * F_b)] \qquad \text{(Li et al., 2001a).}$$

NU = nutrient uptakes by species

When $CR_{ab} > 1$, the competitive ability in taking up nutrients of crop A is more efficient than that of crop B. At least, the cumulative relative efficiency index (REI_c) is a measure that compares the proportional change in total dry matter within a given time interval of one species relative to another:

$$REI_c = K_{corp\ a}/K_{crop\ b} \qquad \text{(Hauggaard} - \text{Nielsen et al., 2006).}$$

$$K_{crop\ ab} = \text{dry matter}_{ab} \text{ at time } t_2/\text{dry matter}_{ab} \text{ at time } t_1$$

3 A Traditional Cropping System as a Contribution to Sustainable Agriculture in China

Historically, intercropping has already been proven for the Dong Zhou and Qin dynasties (770–206 BC) as a special form of crop rotation. Initiated from cropping of forests together with grains or cereals, the intercropping practice went further on with hemp, soybean, mung bean, rice and cotton as well as a system of intercropping of grains with green manure plants.

One of the early and important written documents about crop rotation and intercropping as a sub-item was the "Important Means of Subsistence for Common People", dated back to the period of Wei and Jin dynasties (200–580 AD). It pointed out the possibility to improve soils by multiple cropping of red bean, mung bean and flax and described the theoretical and technical basis for proper rotations of leguminous plants and cereals. During the Ming Dynasty (1368–1644), the "Complete Works of Agronomy" was written by the agronomist Xu Guangqi, who summarized his experience on intercropping of wheat and broad bean (Gong et al., 2000). Besides, multi-component systems with some pertaining to intercropping are often reported in ancient literature, e.g. "Essential Farming Skills of the People of Qi" (~600 AD), "Agricultural Treatise of Chen Fu" (1149) and "Complete Treatise on Agriculture" (~1600) (Li, 2001).

In ancient Chinese agronomy literature it is postulated that farming activities should be in accordance with seasons, climate, soil conditions and nutrient input. Ellis and Wang (1997) showed in their regional field study on traditionally cultivated and used agroecosystems in the Tai Lake Region that these systems were capable of sustaining high productivity for more than nine centuries. Further, Chinese philosophers always pronounced the harmonious relationship between humans, nature and environment, e.g. Zhou Yi's famous treatise "The Book of Change" or the Yin and Yang theory (Li, 1990), which had profound influence on the practice and formulation of integrated farming systems in modern Chinese agriculture policies, e.g. China's Agenda 21. This Agenda, approved on 23 March 1994 in the form of

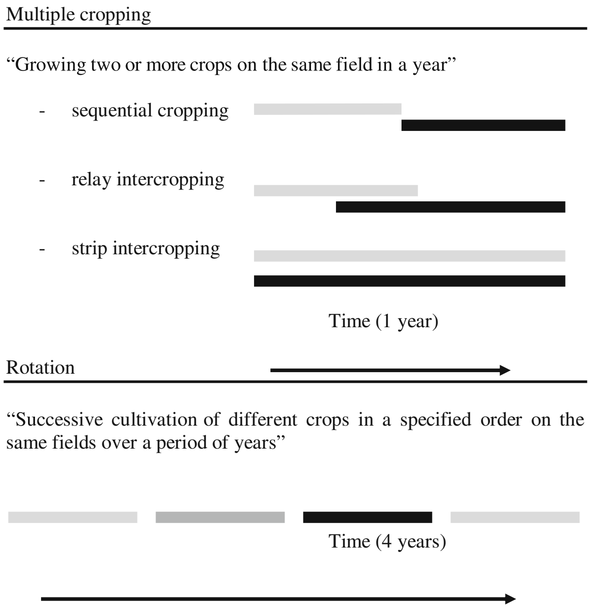

Fig. 4 Differences between and definitions of rotation, multiple cropping and intercropping (Graphic taken from Wageningen University, presentation 2002, definition of rotation added by the author)

the White Paper on China's Population, Environment and Development, lays down some basic principles for the comprehensive management of a sustainable agricultural development. As a consequence, Chinese Ecological Agriculture, not to confuse with European Organic Farming, puts a great deal of emphasis not only on the protection of the environment and the saving of resources but on the all-around development of the rural economy and specifically on rural income-generating activities (Sanders, 2000). Intercropping might be one suitable strategy.

In a public western view, modern agricultural development, except some European organic farming labels, has less to do with ancient philosophy, but more with intensive monocultures (cash crop), extensive use of energy, fertilizer and pesticides and machinery replacing manpower and human labour force. Considering the actual agricultural situation in China (Lin, 1998; Lüth and Preusse, 2007) – production as well as markets – intercropping as a well-adapted cropping system in this country is an option to solve the massive environmental problems caused by high use of fossil-energy-based inputs and a non-resource-preserving agriculture. Hence, a traditional cropping system could turn out to be a modern one (Lu et al., 2003; Zhen et al., 2005).

Intercropping is known as a system being more efficient in poorer soil and environmental conditions – because of a higher uptake and utilizing efficiency of resources like nutrients – and low-input cultivation, but losing this advantage in high-input cultivation. A theory about intercropping and input level says that the productivity of intercropping systems is higher than for pure crop situations when the input is low, but that this advantage decreases as the inputs increase (Wubs et al., 2005). Besides, seriously managed intercropping grants an option for a sustainable low-input cropping system with some kind of rotation effect, reducing pests and weeds, reducing reliance on energy-intensive farming inputs and therefore less eutrophication and emission, improving soil erosion control and, after all, giving economic benefits.

The enormous increase in grain yield and production per capita in the last 50 years in China appeared mostly due to the increased industrial energy inputs, especially in the form of chemical fertilizer (Tong et al., 2003) and irrigation water (Binder et al., 2007). It is not only to increase yield, but to compensate for the loss and degradation of the best lands through industrialization, erosion and soil misuse because of excessive irrigation, unadjusted cropping systems and chemical fertilizer.

For example, in the middle reaches of Heihe River in the Hexi Corridor region, the change of cultivation modes – crop–grass intercropping instead of monocropping – intimated a reduction in soil wind erosion and a halt in sand entrainment (Su et al., 2004). In this region it occurs that dust transport from farmlands is about 4.8–6.0 million tons per year and consequently higher than that of sandy desert dust transport in the same region.

In entire China, the use of mineral fertilizers grew more than 50 times from 1962 (0.63 million tons) to 1994 (33.18 million tons) with 80% being N fertilizer (Inal et al., 2007). The average fertilizer consumption in 2002 was 277.7 kg ha^{-1} arable land (FAO, 2006), rising in the irrigated areas to 450 kg ha^{-1}. Considering N-fertilization amounts, China ranks first in the world. Simultaneously, the yield per unit chemical fertilizer use decreased from 164 (rice), 44 (wheat) and 93 (maize) kg kg^{-1} in 1961 to 10 (rice), 6 (wheat) and 9 (maize) kg kg^{-1} in 1998 (Tong et al., 2003). This decline appears as a result of fertilizer saturation, soil degradation, strong soil, atmosphere and water pollution and poor and low-quality land use. Further, more than 100,000 people were poisoned by pesticides and fertilizers during 1992–1993, and more than 14,000 of them died (Sanders, 2000). Thus, low-input cropping systems sometimes yielding (economically) as high as high-input cropping systems are to be favored, further offering the change to save natural and ecological resources.

China is such a large country that any land use (Xiaofang, 1990) change would contribute greatly to changes in the global world (Tong et al., 2003). The country is known as an important source of methane from rice paddies as well as atmospheric nitrous oxide generated by the increasing use of large amounts of low grade and highly volatile ammonium bicarbonate fertilizers. In contrast, China has an urgent demand for food for a rapidly growing population (Gale, 2002; Lu and Kersten, 2005; Ministry of Agriculture of the People's Republic of China 2004). Only 25.7% of Chinese agricultural area is suitable for arable land usage, with 2.2% being permanent crops (FAO, 2006). With 1.32 million people, China has 20% of the world's population but only 9% of the world's arable cropland. There is only 0.1 ha per capita, which is one-third of the world's average (Wen et al., 1992). Following Tong et al. (2003), more than 60% of all cultivated land is poor in nutrients, and only 5–10% is free from drought, water logging or salinity. Two percent of China's total land area can be considered desertified by human-induced resource degradation (Sanders, 2000). This shows that China has a great demand for resource- and environment-saving agriculture systems being able to feed the country. Intercropping as a widely practiced and accepted cropping system could contribute to a more sustainable land use in this context.

In respect of the enormous environmental problems, like water shortage and pollution, over-fertilization, high nitrous emissions, leaching, soil degradation, erosion, etc., caused by agriculture in China, sustainability is an increasing factor to consider in future preventing natural catastrophes and preserving production levels (Lei, 2005). Climate change and resulting implications for sustainable development was a topic in the Regional Implementation Meeting of the United Nations Economic and Social Commission for Asia and the Pacific, held in November 2007. Around 15.5% of the GDP in 2006/2007 in China came from agriculture, animal husbandry and forestry, though more than 50% of the population depends on agriculture for their livelihoods and hence, a large proportion of the population depends on the climate and the climate change (Prabhakar, 2007). For 2050, the UN figures on scarcity of freshwater availability affecting more than a billion people in Central, South, East and South-East Asia. Additionally, crop yields are predicted to decline in parts of Asia between 2020 and 2050 about 2.5 to 30%. Freshwater availability, droughts and floods due to greenhouse gas emissions, water pollution and soil degradation will be the main problems. Therefore, natural resource and integrated ecosystem management are identified to be major priority actions. The Commission accentuated clearly (Prabhakar, 2007): "Revisiting the existing cropping patterns and systems is needed". As monocropping means higher risk, in terms of income security, nutritional diversity in rural areas and the possibility of severe impacts to large areas due to pest and disease outbreak in a changing climate, mixed and intercropping practices are the only alternative that may have multiple benefits.

4 The Nature and Extent of Chinese Intercropping

One-third of China's cultivated land area is used for multiple cropping (Fig. 4), and a half of the total grain yield is produced with multiple cropping (Zhang and Li, 2003). At present, about more than 70% of farm products are attributed to the improved multiple cropping systems like rotations or intercropping (Zhang et al., 2004). Between 1949 and 1995, the multiple cropping index, meaning the sown area:arable area ratio, increased from 128% to 158%, according to an increase of 2.7 $\times 10^7$ ha of farmland (Li, 2001). Although, intercropping is only one example of the various aspects of multiple cropping, it is substantial as China's intercropping area is the largest in the world. As an example, in 1995 the area under wheat intercropped with maize was about 75,100 ha in Ningxia, producing 43% of total grain yield for the area (Li et al., 2001a). While the most common agricultural land use in the Heihe River Basin before 1980 was to crop wheat, the intercropping of wheat together with maize increased after 1980. Today, 20% of the agricultural land in this region is sown with wheat, 40% with maize and 40% with wheat intercropped with maize (Yamazaki et al., 2005). Furthermore, intercropping has become the most common cropping system for peanut production in northern China (Zuo et al., 2004). Of 31 provinces 27 have land under peanut production. In 1991, the UNEP granted the Zhang Zhuang region the Global 500 award, given for sustainable farming systems in the sense of Chinese Ecological Agriculture (Sanders, 2000). In this region there were altogether ten different modes of intercropping, including cereals and oil crops and cereals and vegetables.

The most common intercropping types considering cereals or grains are those of wheat and maize, wheat and cotton, wheat and faba bean, wheat and soybean, maize and soybean, maize and faba bean and maize and peanut. Sorghum and maize are often used to enclose fields. In addition, there is a vast range of possible combinations of grains together with vegetables. Rice is mostly cultivated in the south where most of the high-quality land is found. In contrast, wheat is cultivated in central China and in the north, and maize is cultivated in central, the northeast and the north of China. The center of cereal production moved slightly towards northern China (Tong et al., 2003), with the North China Plain being China's granary. Various inter- or relay-cropping patterns are practiced mainly in the north, the northeast and northwest and the southwest, especially in Xinjiang, the corridor in the Gansu, Yinchuan plain, Hetao in Inner Mongolia, the Northeast Plain, the North China Plain, along the Yangtze and Yellow rivers, and also in lower dry lands and in hilly areas of South China (Ren, 2005). Wheat intercropped with maize has become increasingly popular in the irrigated area of the Hexi Corridor in the Gansu province,

Fig. 5 Average field size in China is very small, so the collectivity of field borders can be considered as intercropping in a larger scale (pictures: Feike, T.). Typical sequential borderlines in the North China Plain are between soybean, cotton, maize or sorghum, various vegetables, especially cabbage, and interjacent poplar trees

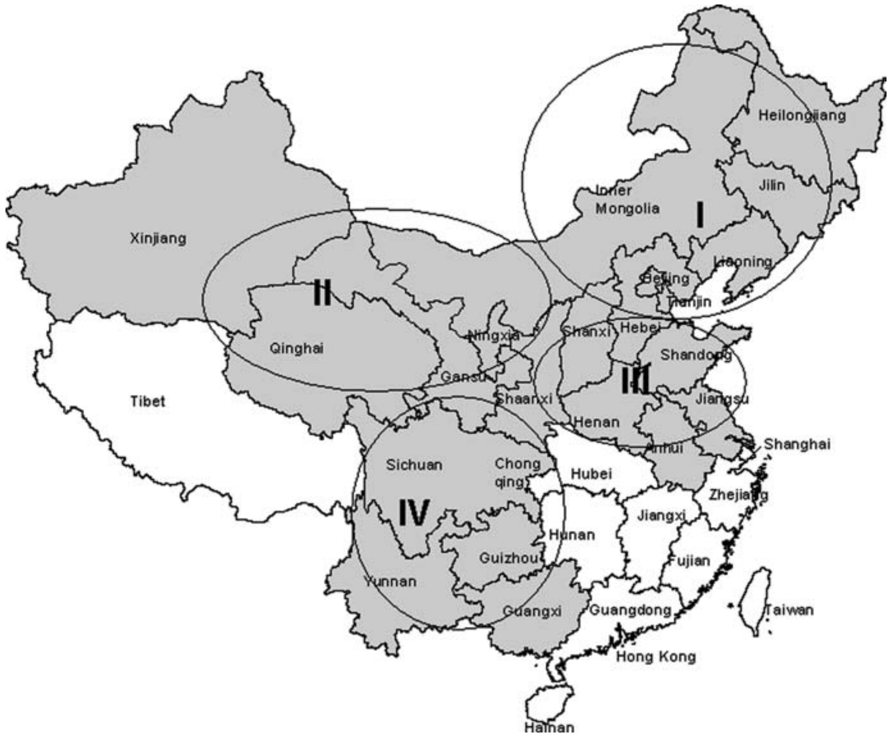

Fig. 6 Provinces where intercropping with cereals is popular (*grey*); regions where intercropping with cereals is less common (*white*) (Graphic taken from USDA, 2007, marking of intercropping regions added by the author). In a rough and simplified visualization, China can be classified into four intercropping regions I to IV: Going from Northeast and North (I) to Northwest (II) and Yellow-Huai River Valley (III) and finally to Southwest (IV) the cropping systems change from one crop a year (I + II) with a great potential for intercropping to relay intercropping (III) of especially maize and wheat and double cropping systems and at least three cropping seasons per year (IV) with different kinds of rotations, and rotations replacing intercropping

along the Huanghe River in Ningxia and in Inner Mongolia regions (Zhang and Li, 2003). In China's northwest, wheat/soybean and maize/faba bean intercropping systems are well established, and peanut/maize intercropping is widespread in the northern parts of the country (Zhang and Li, 2003). In the southwest, wheat–maize intercropping predominates within irrigated spring maize cropping systems. Also within rainfed spring maize cropping systems, intercropping is common. Especially in Sichuan province, wheat–maize intercropping is the most common agroecosystem model (Meng et al., 2006) (Fig. 6).

5 Intercropping Types and Regions

There are different approaches to divide China's agricultural land into specific agricultural regions. The most common is to partition the country into nine, respectively ten, agricultural regions (Guohua and Peel, 1991) situated in middle and eastern parts of China, depending on percentage of cultivation, climatic features and production systems. The agricultural region boundaries are not necessarily authoritative. The agriculture production system zone code of the PR China actually splits the country into 12 zones (FAO, 2007). As the title already tells, the production system – whether it is single or multiple cropping, cropping for uplands or paddy field – is decisive. Meng et al. (2006) analyzed the various cropping systems and potential production with regard to maize production, and divided China's cultivated land into six agricultural regions depending on significant differences in maize cropping patterns and practices.

Concerning intercropping, China's cultivated land can be classified into four main types and regions – illustrated in Fig. 6 – which is just a first and general approach to classify intercropping regions at all because there has been no detailed statistic or documentation dealing with intercropping in particular so far. This basic classification takes the underlying potential for intercropping and the intercropping practice into account (Atlas of the PR of China, 1989; Meng et al., 2006). In general, the agricultural regions in the north, northeast and northwest have more potential for intercropping than the regions in the south, even if the southeast has the highest average precipitation per year, a subtropical, humid and monsoonal climate and with around 135–242%, the highest multiple cropping index in China. The southwest is a very important agricultural region for China with a great diversity of crops, fruits and vegetables, but the climate conditions allow more flexible rotations, thus replacing intercropping systems. Going from north to south the cropping systems change from one crop a year with a great potential for intercropping to relay intercropping of especially maize and wheat and double cropping systems and at least three cropping seasons per year with different kinds of rotations and increasing number of paddy fields (Table 4).

5.1 Type I: Single Cropping with Great Intercropping Potential

The Northeast is characterized by a cold-temperate/semi-humid and temperate/humid climate zone in the north of the agricultural zone and temperate continental monsoonal climate zone. But there are also temperate, humid, monsoonal to subtropical, semi-humid, monsoonal climate conditions to be found.

In the North, there is a warm-temperate, semi-humid, monsoonal and also temperate continental climate. Dark brown soils, phaeozems, chernozem-castanozem-dark loessial soils, brown soils and cinnamon soils are predominant with high accumulation of organic matter. Especially in the Northeast, the soils tend to be slightly acidic or calcareous, with the latter being a problem for, e.g., peanut production. In calcareous soils, the Fe availability is weak because of immobilization of Fe in alkaline soils. Peanut is an important crop in this region, and the disadvantage of Fe availability can be remedied through intercropping as shown later.

In both, Northeast and North of China, with the provinces and municipalities Liaoning, Jinlin, Heilongjiang, parts of Inner Mongolia, Beijing, Tianjin, parts of

Table 4 Intercropping types and regions and their characteristics and potentials* in China

Agricultural region	Cropping conditions and characteristics	Intercropped species	Type of production
Northeast (NE) and North (N): • Liaoning • Jinlin • Heilongjiang • Parts of Inner Mongolia • Beijing • Tianjin • Parts of Hebei • Parts of Shanxi	*Climatic features: middle to warm temperate zone* *> 10°C accumulated temperature (°C)*: NE: 1,300–3,700 N: 200–3,600 *Average temperature (°C)*: –12 to –14 *Sunshine (hours)*: 2,300–3,200 *Frost-free period (days)*: 100–200 *Rainfall (mm/year)*: NE: 500–800 N: 200–600 *Altitude (m)*: 50–100 *Soils: siallitic and calcareous soils predominant* Dark brown soil and phaeozem zone; chernozem-castanozem-dark loessial soil zone; brown soil and cinnamon soil zone *Multiple cropping index (%)*: 0–135	Maize/**soybean Maize/peanut Maize/potato Wheat/broomcorn millet	*TYPE I: single cropping with great intercropping potential* • crops: maize, soybean, spring wheat, rice, sorghum, millet, sesame, potato, sugar beet, flax, peanut, ambary hemp, cotton • yield and production level of cereals: 5,155 kg ha^{-1} • irrigated area (1,000 ha): 1765.2 • consumption of chemical fertilizer (10,000 tons): 118.2

Table 4 (continued)

Agricultural region	Cropping conditions and characteristics	Intercropped species	Type of production
Northwest: • Gansu • Qinghai • Nigxia • Xinjiang • Parts of Inner Mongolia • Parts of Shaanxi	*Climatic features: cold temperate to subtropical zone* *> 10°C accumulated temperature (°C)*: 2,000–4,500 *Average temperature (°C)*: 0–12 *Sunshine (hours)*: 2,600–3,400 *Frost-free period (days)*: 140–170 *Rainfall (mm/year)*: 10–250 *Altitude (m)*: 300–3,000 *Soils: gypsum-bearing and calcareous soils predominant* subalpine meadow soil zone; brown desert soil zone; grey dessert soil zone; sierozem-brown calcic soil zone *Multiple cropping index*: 0–135	Maize/potato Maize/bean Wheat/maize Wheat/buckwheat Wheat/millet Wheat/tobacco Wheat/soybean	*TYPE II: single cropping for cold climate and semi-arid crops to double cropping for irrigation farming* • crops: maize, wheat, millet, broomcorn millet, oats, buckwheat, potato, highland barley, sorghum, rice, rape, soybeans, sugar beet, cotton, flax, hemp, peanut, pea, broad bean • yield and production level of cereals: 4,228 kg ha^{-1} • irrigated area (1,000 ha): 1438.2 • consumption of chemical fertilizer (10 000 tons): 75.6

Table 4 (continued)

Agricultural region	Cropping conditions and characteristics	Intercropped species	Type of production
Yellow-Huai River Valley: • Parts of Hebei • Parts of Shanxi • Shandong • Henan • Parts of Shaanxi • Parts of Anhui • Parts of Jiangsu	*Climatic features: warm temperate to subtropical zone* *> 10°C accumulated temperature (°C)*: 3,400–4,700 *Average temperature (°C)*: 10–14 *Sunshine (hours)*: 2,200–2,800 *Frost-free period (days)*: 170–220 *Rainfall (mm/year)*: 500–1,100 *Altitude (m)*: 50–100 *Soils: calcareous soils predominant* Brown soil and cinnamon soil zone; yellow brown soil and yellow cinnamon soil zone *Multiple cropping index*: 1–190	Wheat/maize Wheat/cotton Maize/soybean in rotation with wheat Wheat/garlic in rotation with maize	*TYPE III: double cropping with potential for relay intercropping* • crops: maize, wheat, soybean, peanut, cotton, vegetable, millet, potato, sorghum, sweet potato, rice, sesame, ambary hemp, tobacco, pea, sugarcane • yield and production level of cereals: 4,876 kg ha^{-1} • irrigated area (1,000 ha): 3369.2 • consumption of chemical fertilizer (10,000 tons): 297.9

Table 4 (continued)

Agricultural region	Cropping conditions and characteristics	Intercropped species	Type of production
Southwest: • Parts of Guangxi • Sichuan • Chongqing • Guizhou • Yunnan • Parts of Shaanxi	*Climatic features: subtropical to tropical zone* *> 10°C accumulated temperature (°C)*: 3,500–6,500 *Average temperature (°C)*: 15–18 *Sunshine (hours)*: 1,200–2,600 *Frost-free period (days)*: 240–360 *Rainfall (mm/year)*: 800–1,600 *Altitude (m)*: 200–3,000 *Soils: ferrallitic and ferro-siallitic soils predominant* Alpine meadow soil zone; subalpine meadow soil zone; read earth and yellow soil zone; lateritic red soil zone *Multiple cropping index*: 135–242	Maize/beans (sorghum) in rotation with wheat Maize/potato/wheat Wheat in rotation with maize/soybean (green bean) Maize/beans in rotation with wheat Maize/wheat Wheat in rotation with maize/sesame Wheat/vegetable in rotation with sweet potato/maize/soybean Maize/sorghum in rotation with wheat Maize in rotation with maize/sweet potato Maize/potato in rotation with wheat Rice/wheat Rice/rape Potato/maize Maize/cassava in rotation with soybean Maize/soybean in rotation with sunflower Wheat in rotation with maize/sesame-maize/potato Vegetable in rotation with maize/sweet potato Maize/sweet potato in rotation with wheat/vegetable Rape/maize Wheat/vegetable in rotation with maize/vegetable	*TYPE IV: three cropping seasons per year with rotations replacing intercropping* • crops: rice, maize, wheat, sweet potato, sorghum, rapeseed, sugarcane, peanut, tea, cotton, ambary hemp, tobacco, millet, cassava, soybean, pea • yield and production level of cereals: 4,605 kg ha^{-1} • irrigated area (1,000 ha): 1349.2 • consumption of chemical fertilizer (10,000 tons): 140.3

* Source: Atlas of the PR of China (1989); Meng et al. (2006); National Bureau of Statistics of the Peoples Republic of China, 2006; The National Physical Atlas of China = Chinese Academy of Sciences (1999).
** meaning "intercropping".

Hebei and Shanxi, intercropping is widespread. The climatic features allow only one crop per year. The average precipitation is between 200 and 800 mm/year with rain falling mainly in summer, whereas spring droughts are frequent. The winters are long and cold, and there is a large daytime–nighttime temperature gap during the whole growing season. In addition, the average temperature is very low. The varieties grown in this region have to be fast-maturing varieties. Only crops which prefer semi-moist and warm conditions can be grown, thus reducing the cultivation range to especially maize, soybean, peanut, potato, spring wheat and millet. Generally, the production system is based upon rainfed conditions. In Hebei, Shanxi and around Beijing, irrigation is also practiced. In the northeast as well as in the north, intercropping can provide an optimal site utilization, a higher yield compared to monocropping and an improved diet diversification.

5.1.1 Intercropping Maize with Peanut

Peanut is the major oilseed crop in China constituting 30% of the land's total oilseed production and 30% of the cropped area (Zhang and Li, 2003). But especially in north China with its calcareous soils, iron deficiency chlorosis is often observed and Fe deficiency is one of the most common yield-limiting nutrients that causes serious economic problems in peanut monocropping systems (Zuo et al., 2004). Maize has a great potential to improve the Fe nutrition of peanut within an intercropping system by rhizosphere interactions (Fig. 7). In an experiment of Zhang and Li (2003), young leaves of peanut plants in rows 1–3 from the maize grew without visible symptoms of Fe deficiency, while those in rows 5–10 showed a variable degree of chlorosis. They were all chlorotic when roots were separated. Peanut is a strategy I, and maize a strategy II species. Strategy I plants respond to Fe deficiency with increased ferric reductase activity of roots and acidification of the rhizosphere by releasing protons from the roots. Strategy II plants excrete phytosiderophores into the rhizosphere thus being more efficient in Fe deficiency surroundings. They mobilize Fe (III) and benefit the iron nutrition of maize as well as peanut (Marschner, 1986).

The results indicate the importance of intercropping systems as a promising management practice to alleviate Fe deficiency stress (Inal et al., 2007), because soil amendments and foliar application of Fe fertilizers are usually ineffective or uneconomical for correcting Fe chlorosis. But in addition and especially in calcareous soils, the effects of soil moisture on soil iron availability under intercropping could be more complicated compared to monocropping. Zheng et al. (2003) showed that the Fe nutrition of peanut intercropped with maize could be affected by soil moisture condition. Root growth of peanut was significantly inhibited at 25% soil water content compared to those at 15% soil water content. Also, chlorophyll content in the new leaves of intercropped peanut decreased and leaves became chlorotic at 25% soil water content.

The improved Fe availability is the underlying reason for an increased N uptake. Competitive interactions between maize and peanut for N and improvement of Fe uptake by peanut were likely to be important factors affecting N_2 fixation of peanut (Zuo et al., 2004). Also the nitrate concentration in the soil rhizosphere of

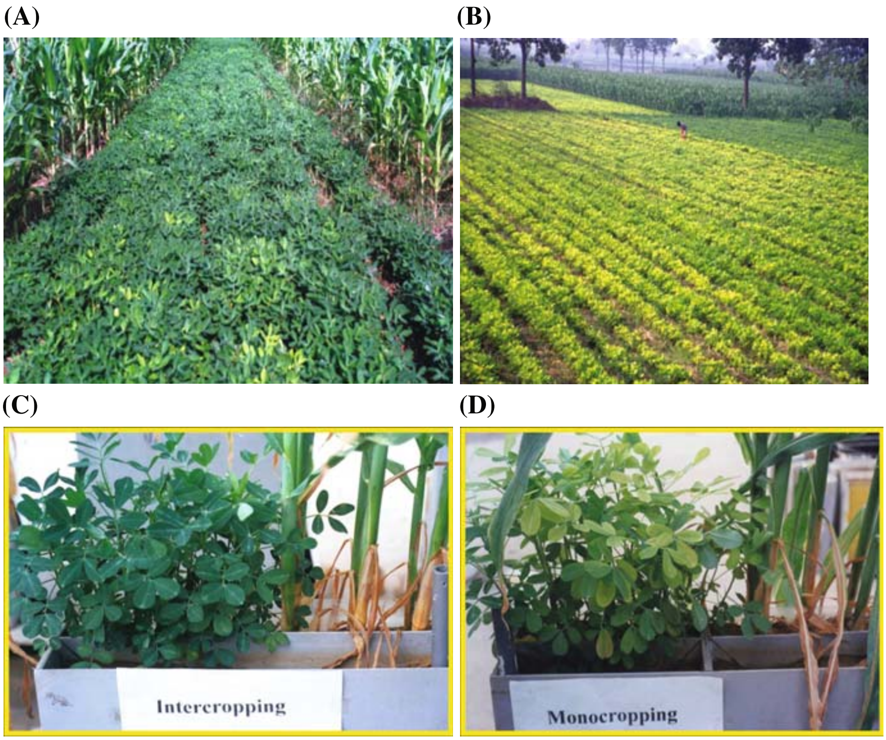

Fig. 7 Intercropping of maize and peanut reduces iron chlorosis in peanuts on calcareous soils (pictures: Zhang, F.). (**A/B**): Differences between (strip) intercropped (l.) and monocropped (r.) peanut in the field. (**C/D**): Differences between intercropped (l.) and monocropped peanut (r.) in a pot experiment. In the pot experiment as well as in the fields, peanut shows less Fe chlorosis when intercropped with maize

intercropped peanut did not increase, nor did the N uptake by peanut compared to sole stand. The authors concluded that the improvement in Fe nutrition was an important factor promoting N_2 fixation by peanut. The competition for N between maize and peanut was not the stimulating factor for N_2 fixation, but the increased Fe availability and uptake by peanut. Both peanut and the root nodule bacteria require Fe for many metabolic functions at several key stages in the symbiotic N_2 fixation. Furthermore, high levels of soil nitrate can be a potent inhibitor of N_2 fixation because then the legumes thrive without fixing atmospheric N (Zuo et al., 2004). Competition for N in a cereal/legume mixture acts as a stimulator for N_2 fixation.

5.2 Type II: Single Cropping for Cold Climate and Semi-Arid Crops to Double Cropping for Irrigation Farming

The north-western intercropping region includes the provinces Gansu, Qinghai, Nigxia, Xinjiang, parts of Inner Mongolia and parts of Shaanxi. In comparison to the provinces in the North and the Northeast, the Northwest of China has higher average temperature and more frost-free days, but the average precipitation with 10–250 mm per year is very low. The climate is temperate continental and subtropical, humid in the east and west of the agricultural region changing to dry, continental temperate in the middle. There are long, cold winters and short, hot summers with temperature shifting greatly from day to night as well as from season to season. The crops and varieties grown are fast-maturing ones. Usually, the region was a one harvest-one year district and intercropping wheat with soybean, wheat with millet and maize with faba bean was the main planting system before 1960. From the 1960s onwards, relay intercropping systems with wheat and maize established more and more due to irrigation and varieties improvement. The improvements also led to a gradual shift to a double cropping system in irrigation farming. Although the Northwest is a typical intercropping region with a long intercropping tradition and with intercropping systems being more differential than in the Northeast and the North, the potential for intercropping changes in direction from strip intercropping to relay intercropping and finally to double cropping. Nowadays, intercropping practice in this region is almost all relay intercropping of wheat and maize or wheat and cotton.

5.2.1 Intercropping Wheat or Maize with Legumes

Intercropping wheat with faba bean or soybean increases the yield of wheat in nearly all studies: yield and nutrient acquisition by intercropped wheat and soybean were all significantly greater than for sole wheat and soybean (Li et al., 2001a). Here, intercropping advantages in yield were between 28% and 30% for wheat/soybean. Wheat/soybean had also significant yield increase of intercropped wheat over sole wheat in the study of Zhang and Li (2003). Intercropping resulted in a yield increase in wheat as well as in faba bean between 7% and 46% (Song et al., 2007).

One reason is the effect intercropping has upon N uptake and availability. Zhang and Li (2003) showed that yield increased of about 53% in wheat/soybean, where aboveground effects contributed 23% and belowground effects contributed 30%. For increased N uptake they measured a contribution of 23% aboveground effects and 19% of belowground effects, resulting in an increased overall N uptake of 42%. In contrast to soybean wheat had a greater capability of acquiring nutrients because of the enhanced aggressivity of wheat over soybean. A greater competitive ability and aggressivity of wheat as well as the better nutrient CR led to a greater capability of wheat to acquire nutrients, concerning not only N, but also P and K (Li et al., 2001a). The N accumulation by wheat was mainly due to increased border row N uptake which shows that intercropping is based upon an edge effect.

Besides nutrient acquisition, additional components like border row effects contribute to the overyielding of intercropped wheat. Yields of wheat in border rows significantly increased compared with yield in the inner rows or in rows of sole. Zhang and Li (2003) pointed out that out of a 64% overall increase in yield in intercropped wheat, about 33% came from inner-row effects and about 67% came from the border-row effects. The higher crop overyields due to extra sunlight that taller crops receive on their borders. But accordingly, the N and P accumulation in the border row were significantly greater than in inner row or in sole wheat. Both, border row and inner row contributed to the increase in yield. Studies of Cruse (1996), Ghaffarzadeh (1999), Leopold Center (1995) and Zhang and Li (2003) mentioned that four to six rows seem to be the optimum. Up to six rows a mixed stand is comparable to a sole stand.

The main advantage of intercropping wheat with a legume like soybean or faba bean is the complementary N use; that means, wheat competes much better for soil-available N than the legume and, conversely, the legume is forced to get nitrogen from atmospheric N fixation. The competition from wheat in acquiring N through intermingling roots enhanced N_2 fixation in faba bean by about 90% (Xiao et al., 2004). In addition, there is a small N transfer from faba bean to wheat between 1.2% and 5.1% of faba bean N, according to the used measuring techniques, the root distance and contact. This supports the hypotheses of N-sparing by faba bean due to increased N_2 fixation and the increased resource-use efficiency by cropping wheat and a legume together.

Nevertheless, the enhanced N availability or uptake of a cereal crop combined with a leguminous plant like faba bean is more investigated by intercropped maize than intercropped wheat. As shown, the belowground interactions between intercropped species can be more important than aboveground interactions. Intermingling of roots makes sure that nutrients can be used more efficiently because of different mobilizing processes, leading to a higher yield (Li et al., 2007; Zhang and Li, 2003; Zhang et al., 2004). Intermingling of maize and faba bean roots increased N uptake by both crop species by about 20% compared with complete or partial separation of the root system (Li et al., 2003b). The N uptake of faba bean was higher than sole cropped faba bean during early growth stages and at maturity, whereas N uptake of maize did not differ from that by sole maize at maturity, except when P fertilization was high. Because organic acids and protons released by faba bean can mobilize P by the acidification of the rhizosphere, both the N and P uptake by intercropped maize was found to be improved compared with corresponding sole maize (Zhang et al., 2004). Hence, the improved N and P nutrition by intercropping could be characterized as a synergistic process.

A mixture of exudates released from two instead of only one species could change rhizosphere conditions being responsible for the enhanced availability of nutrients, e.g. phosphorus. Zhang and Li (2003) showed in a pot experiment that chickpea facilitated P uptake by associated wheat. Wheat prefers inorganic P and is less able to use organic P. In contrast, chickpea is able to use both P resources effectively. As chickpea mobilizes organic P by releasing phosphatase into the soil turning organic P into inorganic P, P gets available for wheat. Because wheat has a greater competitive ability than chickpea, wheat acquires more inorganic P than chickpea so that chickpea is forced to mobilize organic P. Hence, competition turns into facilitation, because both species do not suffer in P supply. According to the N uptake, P uptake is a combination between above- and belowground effects and interactions. Aboveground interactions contributed 26% to a wheat/soybean mixture, whereas 28% of belowground interactions contributed to the grain yield of wheat (Zhang and Li, 2003).

There are various studies dealing with P supply within intercropping systems, especially maize/chickpea (Inal et al., 2007; Li and Zhang, 2006; Li et al., 2004) and maize/faba bean (Li et al., 2003a/2007; Zhang and Li, 2003). But in most cases, those studies were pot experiments in a greenhouse and not field experiments. Experiments with chickpea promote scientific knowledge of plant nutrition being different whether there are inter- or monocropping conditions, but indeed chickpea is not popular in Chinese cropping systems.

Nevertheless, similar to wheat grown together with chickpea, maize intercropped with chickpea too profits by the intermingling of their root systems. Both, faba bean or chickpea and maize accumulated more P in the shoot when intercropped (Li et al., 2003a). The total P uptake by intercropped maize supplied with phytate was twofold greater compared to a monoculture (Li et al., 2004). Li et al. (2004) indicated clearly that the improved growth of maize when intercropped with chickpea was not caused by better N nutrition, but better P uptake. According to Li et al. (2003/2007) four explanations for the increased P uptake by diverse species are plausible:

(1) Greater phosphatase activity in the rhizosphere in intercropping decomposed soil organic P into an inorganic form, which can be used by both species.
(2) Improved P nutrition in maize could have resulted from an increased uptake of P released during the decomposition of root residues after the harvest of e.g. faba bean.
(3) Faba bean, for example, was better nodulated when intercropped, resulting in more fixed N_2. While fixing atmospheric N, legumes take up more cations than anions and release H^+ from the roots. Again, H^+ is important in dissolving P in calcareous soils.
(4) The volume of soil exploited by the maize roots increased and led to a greater ability to absorb P.

But considering intercropped wheat, Song et al. (2007) went beyond the N accumulation in a plant and studied the community composition of ammonia-oxidizing bacteria in the rhizosphere of wheat and faba bean at different growth stages. Autotrophic ammonia oxidizers in the rhizosphere carried out the first and rate-limiting step of nitrification, the oxidation of ammonia to nitrate. The authors concluded that these bacteria could play a key role in N availability to plants and could be important for the interactions between plant species in intercropping. During anthesis the nitrate concentrations in the rhizosphere of wheat intercropped with faba bean were nearly twice as high as in monocropped wheat. Song et al. (2007) suggested that N released from faba bean roots was rapidly mineralized to ammonia and then transformed to nitrate.

Intercropping is known to suppress weeds and pests, because of the higher biodiversity in comparison to monoculture. The soil is covered nearly all the time, and the different plants give home to predators. Most studies dealing with the influence of intercropping on pests and weeds investigated these aspects from the point of view of ecology and less from the point of relationships within a cereal–cereal mixture. Li (2001) reported wheat–cotton relay intercropping being able to control the cotton aphid as well as cotton–rape intercropping that reduced insect damage. The cotton aphid is the main pest of cotton and appears in May. In early May the cotton aphid's natural enemy is the seven-point lady beetle, which is also the natural enemy of the rape aphid. This supports strongly the enemies' hypotheses (Andow, 1991) where the intercropping changes the environmental conditions in such a way that the natural enemy activity is increased. Ma et al. (2007) showed that parasitism of *Allothrombium ovatum* on alate aphids can significantly control the population increase of wheat aphids. Within a strip intercropping of wheat together with alfalfa they examined the possibility to improve the biological control of the wheat aphid by the mite *A. ovatum*. The strip intercropping resulted in higher soil moisture, shadier soil surface and thus a changed microclimate which caused adult female mites to lay more egg pods. In addition, the non-furrow areas provided a more suitable habitat for mites' overwintering, so that the mean number of mites per parasitized aphid was significantly higher in intercrops than in monoculture (Ma et al., 2007).

The different microclimate in intercropping compared to monocropping seems to be substantial for suppressing or enhancing diseases. Chen et al. (2006) showed, that under zero N fertilization, the appearance of powdery mildew in a field was similar in intercropped and monocropped cultivation of wheat and faba bean. They supposed that under deficient N circumstances, plant growth is limited, thus leading to a comparable microclimate within both cropping systems. However, under increased N application rates, the microclimate differs regarding velocity of air movements and correspondingly lower humidity. Chen et al. (2006) concluded that conditions that prevailed in intercropped wheat with faba bean are less conductive to infection by and growth of the powdery mildew compared with sole wheat, because the differences in disease incidence and disease severity due to intercropping between zero and increased N application were significant.

5.3 Type III: Double Cropping with Potential for Relay Intercropping

Cereal – especially maize and wheat – production in the Yellow-Huai River Valley is mostly practiced as relay intercropping and less as strip intercropping. Wheat, maize and cotton are the most important and stable crops grown in parts of Hebei, Shanxi, Shaanxi, Anhui and Jiangsu and in Shandong and Henan province. The region is consequently China's granary. With progress in engineering, breeding and irrigation, relay intercropping within the widespread and current double cropping systems is more and more decreasing. In addition, strip intercropping is the only way practised in vegetable production, agroforestry and in fields along big roads. Single cropping with potential for intercropping is common practice in rainfed upland farming, whereas double cropping in large scale or three harvests in 2 years as a more adjusted and sustainable production are to be found in irrigation farming. For the double cropping system, resistant varieties are needed, because of the narrow crop rotation consisting nearly completely of wheat and maize or cotton. Although, summer maize varieties have to be fast maturing because of the very short growing season between June and September/October. Additionally, for implementing two harvests within one year – wheat in June and maize in September/October – an irrigation in springtime would be necessary. About 60–70% of the rain falls during the hot summer. In contrast, the winters are cold and dry. Within the intercropping region, the climate changes from temperate continental to subtropical-humid with clear-cut seasons and plum rains between spring and summer.

5.3.1 Intercropping Wheat with Maize

Intercropping a cereal–cereal association such as wheat and maize become increasingly popular in irrigated areas and in the North China Plain. Both species grow together for about 70–80 days and yield more than 12,000 kg ha^{-1} (Zhang and Li, 2003). Consequently, both species compete strongly for N and light during their co-growth. Because there is no leguminous plant involved or no facilitation concerning P or Fe supply, the competition seems to be more intrinsic. Nevertheless, scientific research (Li et al., 2001a,b; Zhang and Li, 2003) found that grain yield of both species increased and the N uptake and nutrient accumulation was greater than that by corresponding sole cropping under the same N supply. Indeed, during co-growth biomass yield and nutrient acquisition of the earlier sown wheat increased significantly, whereas at wheat harvest, the biomass of maize in the border row was significantly smaller than in sole maize (Li et al., 2001a). But there is a recovery-compensation growth with the result that at maize maturity the disadvantages disappeared with no significant differences in biomass between border-row maize and inner-row maize or corresponding sole maize. First, the subordinate plant suffers but after harvesting the dominant plant is able to compensate. This competition-recovery production principle rests upon the ecological mechanism of niche differentiation. Li et al. (2001b) suggested that interspecific interactions shifted the peak nutrient requirement of dominated species like maize to after wheat harvest, which was helpful for reducing interspecific competition during co-growth. This principle is suitable to intercrop short-season species together with long-season species.

In addition, the more efficient and temporal distribution of soil nutrient consumption results in a reduced nitrate content in the soil profile (Zhang and Li, 2003). The $NO_3{}^-$ amounts after wheat harvest were greatest under sole wheat and smallest under maize intercropped with wheat (Li et al., 2005). The decrease could be amounting to 30–40% in a wheat/maize association compared to wheat or maize sole (Zhang and Li, 2003). Hence, intercropping can reduce nitrate accumulation and eluviation compared to monocropping.

Like biomass production, grain yield and nutrient accumulation, root growth and root distribution show compatibility of species and niche differentiation of plants. At symmetric interspecific competition, where both species are on an equal footing for acquiring factors of growth, e.g. maize intercropped with faba bean, the spatial root distribution is compatible and similar under inter- as well as monocropped cultivation. Faba bean had a relatively shallow root distribution, maize roots spread underneath them. The shallow root distribution of faba bean results in lower competition for soil resources with the deeper-rooted maize. In contrast, asymmetric competition, where one species dominates over another, e.g. wheat intercropped with maize, results from the greater root proliferation of overyielding species underneath the other. Li et al. (2006) showed that intercropped wheat had a greater root length density compared to sole-cropped wheat, occupied a larger soil volume and extended under maize roots. Roots of intercropped maize were limited laterally to about 20 cm, whereas roots of sole-cropped maize spread laterally about 40 cm. The failure of maize to extend into the soil immediately under wheat may help to explain why maize does not respond positively to intercropping until after the wheat harvest (Li et al., 2006).

5.4 *Type IV: Three Cropping Seasons per Year with Rotations Replacing Intercropping*

Cultivation spectrum and species diversity is much wider in the southwest region, including parts of Guangxi and Shaanxi as well as the provinces Sichuan, Chongqing, Guizhou and Yunnan. Among others, rice, maize, wheat, sweet potato, sorghum, rapeseed, sugarcane, peanut, tea, sesame, bean, vegetable, cotton, ambary hemp, tobacco, millet, cassava, soybean and pea are cultivated, mostly within a rotation and a double or even triple cropping system. In southern parts, double and triple cropping including paddy fields get more and more common. In medium and high plateau uplands, double cropping as well as single cropping for paddy fields are practiced. The production account of wheat decreases more and more when going southward, hence rice and paddy fields increase. Climate conditions allow more flexible rotations, thus replacing and reducing intercropping potentials. Nearly the whole year is frost free with an average temperature between 15°C and 18°C. From the North of the intercropping region to the South, the climate changes from subtropical, humid, monsoonal with intense sunlight and long, hot summers but low temperatures to a more and more tropical climate with conspicuous dry and rainy seasons. Average precipitation is between 800 mm and 1600 mm per year with Guangxi being one of China's most rainy areas. Rainy season is between May and October with occasional droughts in springtime.

6 Conclusion

In conclusion this chapter shows that intercropping of cereals has a 1000-year old tradition in China and it is still widespread in modern Chinese agriculture. As sustainability is the major challenge for Chinese agriculture, intercropping bears the potential for a more sustainable land use without introducing a new cropping system. Nevertheless, there are still research gaps considering intercropping pattern improvements. This chapter is a first approach to take stock of intercropping history, practice and distribution in China. Mostly, these factors are only worth footnotes in international literature. Intercropping regions, area, cropping conditions and crops are rarely part of statistics or reviews. The evaluation of available data on intercropping in this chapter has shown that a classification of four Chinese cereal intercropping regions may be possible, even if it is, in fact, an interim and general classification. More detailed data and studies are needed for further specification of intercropping regions and patterns. The four intercropping regions are the Northeast and North, the Northwest, the Yellow-Huai River Valley and the Southwest. Going from north to south the cropping systems change from one crop a year with a great potential for intercropping to relay intercropping of especially maize and wheat and double cropping systems and at least three cropping seasons per year with different kinds of rotations and rotations replacing intercropping.

Maize and wheat cultivation is well documented and the main topic of Chinese studies with irrigation and fertilization practice and improvement taking precedence over interspecific competition. Both crops are mostly intercropped with each other or intercropped with legumes and are common all over Chinese intercropping regions. In most studies, maize yields increased when intercropped. Nutrient efficiency increased while N input could be reduced and simultaneously leaching could be reduced because of lower nitrate in the soil. It seems as if maize is a suitable species for intercropping systems in China. Within the double cropping system of wheat and maize, relay intercropping of wheat and maize is common practice. As the region is China's granary the irrigation area and the fertilizer consumption is the highest compared to other intercropping regions, and it is important to reduce input factors and to produce more sustainable output. Improved and adjusted intercropping systems could contribute, e.g. to replace a single maize cycle with an intercropping system, especially in the system of three harvests in 2 years.

The range of species which can be grown in China, especially in the middle and the south of China, is wide, so that there are various possibilities and combinations of intercropping systems. The peanut production in the northeastern region showed as well that intercropping could compensate soil property deficits by reducing Fe chlorosis in peanut plants when intercropped with maize. As intercropping systems offer great opportunities for a more sustainable cultivation, these systems have to be studied more closely in future.

With floods, droughts, landslides and the snow disaster in February 2008, the consequences of environmental pollution will come more and more into mind. In this context, high-input agriculture and monocropping may not be the best-performing systems any more, considering income security, nutritional diversity in rural areas, and possibility of severe impacts to large areas due to pest and disease outbreak in a changing climate.

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