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Article

How to Overcome the Slow Death of Intercropping in the North China Plain

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Abstract: Intercropping has a strong potential to counteract the severe degradation of arable land in the North China Plain (NCP). However, a rapid decline of intercropping can be observed in the last decades. The present paper investigates the reason for this development and suggests solutions on how to adjust intercropping systems to fit modern agriculture. Firstly, the developments of socioeconomic conditions for farming were assessed, analyzing the statistical yearbooks of the seven provinces of the North China Plain. Secondly, a survey was conducted in the study region to understand the current state and future of intercropping systems. The investigations revealed that, due to limited off-farm income possibilities in the past, intercropping has been a viable solution to intensively use the limited land resources per farm household. However, a shift of rural laborers into other sectors has recently been observed. Thus, decreasing importance of income from agriculture and increasing labor costs are heralding the slow death of labor-intensive intercropping systems. Two possible solutions are discussed in the paper. Either the traditional row-intercropping systems can be transformed into strip-intercropping systems that can be mechanized using existing machinery; or, new machinery has to be developed that enables the mechanization of the traditional row-intercropping systems.

Keywords: intercropping; sustainable agricultural system; adaptation; extinction; agricultural mechanization; China

1. Background

The North China Plain (NCP), one of China's major agricultural regions, experienced strong production and yield increases in the last decades [1]. However, increasing yields are mainly a result of increased inputs of fertilizer, irrigation water and plant protection [2], which further aggravates environmental degradation in the region [3–7]. A production system that has a strong potential to counteract resource degradation while maintaining high yield levels is intercropping. The simultaneous cultivation of two or more crops on the same field is a traditional system in China [8,9]. Due to the differences in canopy architecture, rooting pattern and nutrient requirements of the two companion crops in such a system, the growth factors water, nutrients, and solar radiation can often be used more efficiently, which leads to a higher yield from intercropping compared to its monocropping equivalents [10–13]. When combining different crop types, weed and pest pressure are lowered and input of herbicides and pesticides can be reduced [14,15]. Intercropping can lead to higher yields while saving resources, controlling erosion, and reducing nutrient leaching [16–18].

In recent years, the number of publications on intercropping in China has increased strongly (e.g., [11,13,16,19–22]). Different research groups examined various aspects of intercropping systems, several of them conducting field experiments in the NCP. Research concentrated on agronomic aspects of the systems, mainly yield advantages and below-ground resource capture. The results significantly contributed to increasing the knowledge on various agronomic aspects of intercropping systems in China and worldwide.

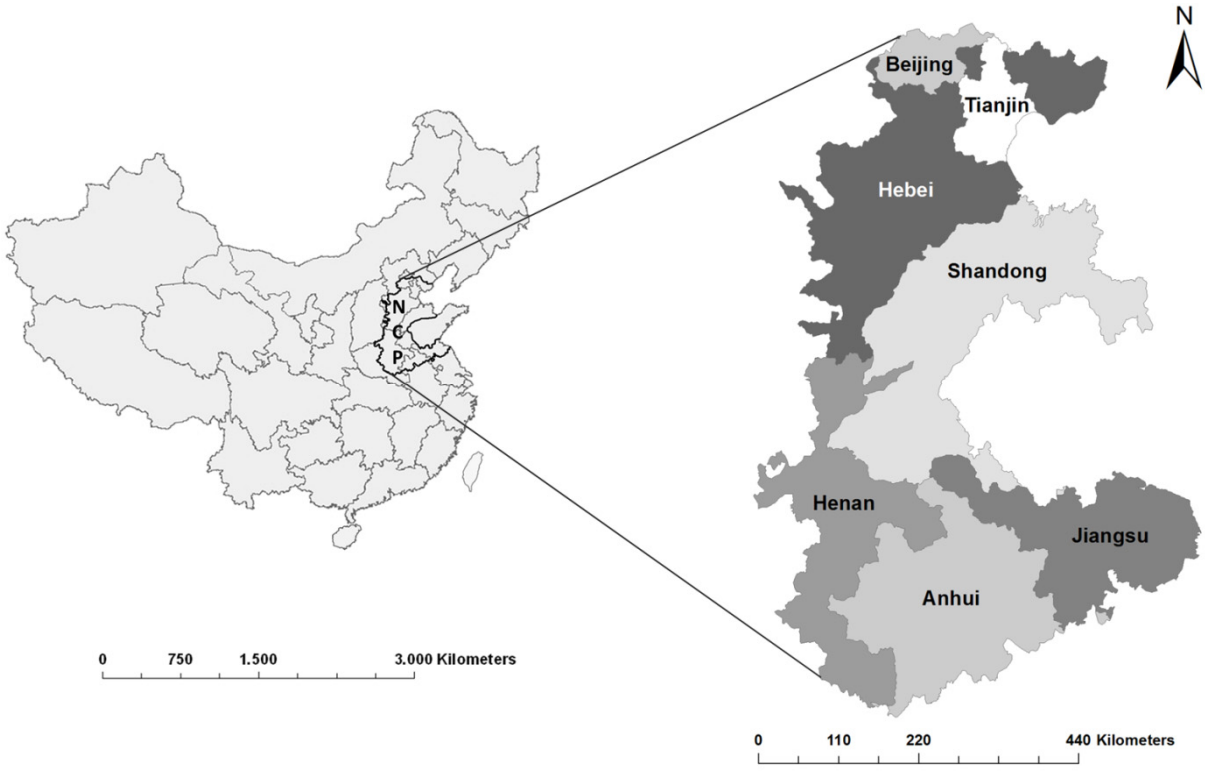
However, one important question was still insufficiently answered after intensive literature review: What is the actual importance of intercropping in China? When referring to land under intercropping cultivation, most papers unfortunately refer either to sources written in Chinese, published in the beginning of the 1990s (e.g. [22]), or they do not even clarify where the information originates from [23]. When we compare the often cited estimations of Tong [24] that "one third of all Chinese grain being produced in intercropping systems" to our field observations, we identify a huge gap. After several years of field research, including extensive travels to most parts of the NCP, we want to reduce the former estimations to around five percent of arable land as being under current intercropping cultivation. There is strong evidence that the area under intercropping cultivation, and thus the importance of intercropping, suffered a tremendous decrease in the last two decades.

Intercropping can only have a significant contribution to sustainable food production in the NCP, if it is widely practiced. It is therefore of great importance to understand why intercropping is losing ground in contemporary China and what could be done to reverse this trend. Thus the present paper aims at i) identifying and analyzing the key trends that impact farmers' decision making and hence farming systems design, ii) exploring the impact of those trends on intercropping practices, so they can be understood and possibly addressed, and iii) synthesizing the findings to develop solutions on how to reverse the observed decline of intercropping in the region.

2. Methods

Two approaches were employed to understand the changes that have taken place in the NCP and determine their impact on intercropping systems. In the first step, the statistical yearbooks on national and provincial level from 1996 until 2010 were analyzed. The aim was to understand and quantify the changes in the socioeconomic and sociotechnical frame conditions for farming in the NCP over the last decades. Therefore the data analysis focused on development of availability of the three major production factors: labor, capital and land. A shift in the availability of those production factors advanced the mechanization of agricultural production in the region, which is additionally analyzed in detail. The analyses of the provincial statistical yearbooks comprise the yearbooks of the seven provinces: Beijing, Tianjin, Hebei, Shandong, Henan, Anhui and Jiangsu, which make up the area of the NCP (Figure 1). When presenting absolute values of the NCP, e.g. "total cultivated area," the sums of all seven provinces compiled from the respective yearbooks were calculated. When per capita data is shown, e.g. "savings deposit per capita," the compiled values of the seven provinces were weighted by the number of capita in the respective province.

Figure 1. Location of the survey region North China Plain (NCP) in China and the location of the seven provinces within the NCP.



In the second step, the current situation of intercropping practices in the North China Plain was evaluated. Therefore a qualitative inquiry was conducted, interviewing farmers, employees of the state extension service and researchers involved in intercropping studies. The inquiry had two main goals: i) identify prevailing intercropping systems in the region, and ii) understand farmers' underlying

motives and concepts of practicing intercropping in the NCP. Semistructured in depth interviews, as described by Case [25], were applied. The interviews with farmers focused on the agronomic details of the practiced intercropping system, the individual intercropping history, and the perceived benefits and drawbacks of the system. Additionally, the interviews with researchers and extensionists addressed the generation and transfer of research findings as well as the perception of farmers' knowledge and motives.

As the goal of the study was to obtain the greatest possible information from the cases in the sample, snowball sampling [26] was applied. The interviews were conducted during several field stays in the North China Plain between autumn 2007 and summer 2011. In total, 35 farmers (21 intercropping, 14 non-intercropping), ten extensionists and seven researchers were interviewed. Due to the homogeneous environmental and socioeconomic conditions of the North China Plain, the sampling size is considered sufficient to create a sound picture of intercropping practices in the region. To ensure the relevance of the sampling structure, interviewees were selected purposefully to cover a wide range of intercropping systems, both in terms of crop combinations and input demand.

By connecting the findings of the statistical data analysis with the findings of the inquiry, the impact of changing socioeconomic conditions on the practice of intercropping are explained. Furthermore, conclusions are drawn on how intercropping systems should be adjusted to fit the changing agricultural production conditions, and be more widely adapted in the NCP in the future.

3. Results

3.1. How Did the Production Conditions of Farming Change in the NCP in the Last Decades?

China's economic development led to strong changes in rural farm households' production factor endowment, which has a severe impact on cropping structures and farming systems. Since the market reforms in the beginning of the 1980s, China has experienced an accelerated economic growth, with a tremendous impact on the labor market (Figure 2).

In the NCP, similar to the developments in other parts of China, the number of laborers, who generate most of their income from agriculture decreased strongly since the beginning of the 21st century (Figure 2). In 2000, still 52.7% of people were employed in the agricultural sector (primary industry), while in 2010, the value dropped to 33.8%. People moved into the industrial and construction sector (secondary industry), as well as the service sector (tertiary industry) [1]. A similar trend can be found when looking at the share of income generated from agricultural household production (Figure 3). During the time of collectivization until 1980 the rural population was mainly employed in the state cooperatives, receiving a monthly salary. With the agricultural reforms however, land rights returned to farmers and farm households started to act as entrepreneurs, generating income from their fields. Since 1985, when the share of income generated from agricultural household production made up more than 90%, a steady decline is happening. In 2005, the share dropped below 70%.

The production factor labor, which had been nearly inexhaustible in rural China in the past is becoming scarcer and scarcer. In the last decades, steadily increasing off-farm income possibilities lead to increasing opportunity costs, with farm households investing less and less time to their farming.

Net incomes of the rural population in the NCP nearly quadrupled in the last 15 years, while average wages of staff and workers increased more than seven times in the same period (Table 1). As a result, the savings deposit in the NCP doubled every five years and reached about 23500 RMB per capita in 2010 from formerly 2500 RMB in 1995.

Figure 2. Development of composition of employment in the three sectors in the NCP from 1995 to 2010 ([1]; compiled by authors).

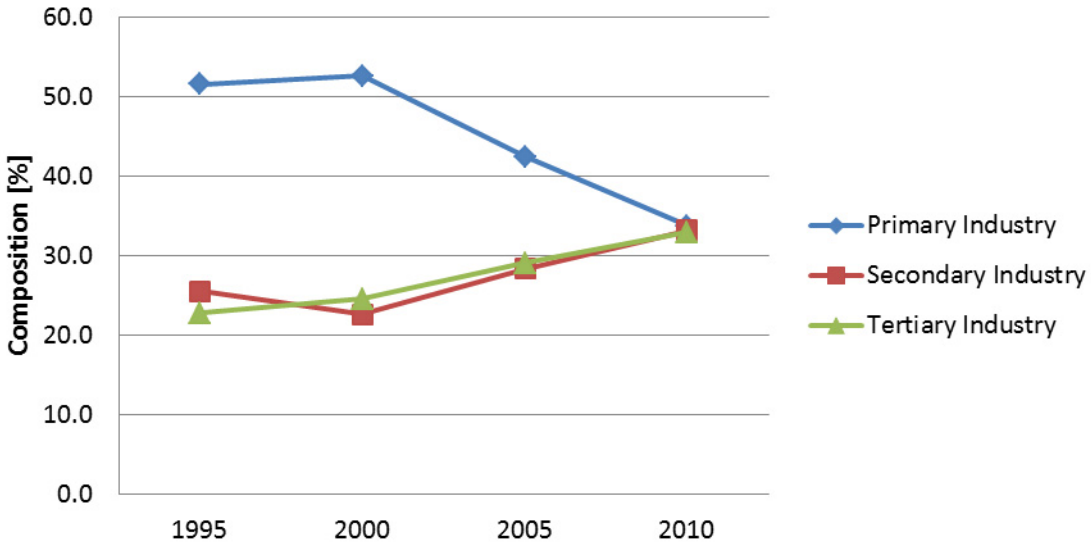
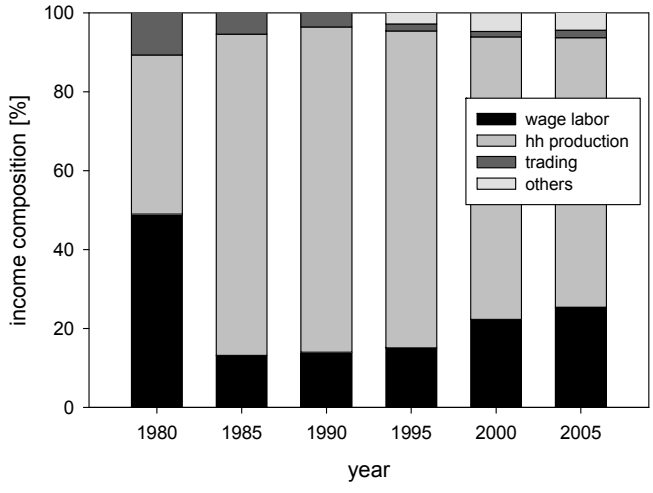


Figure 3. Income composition of rural households in China [27].



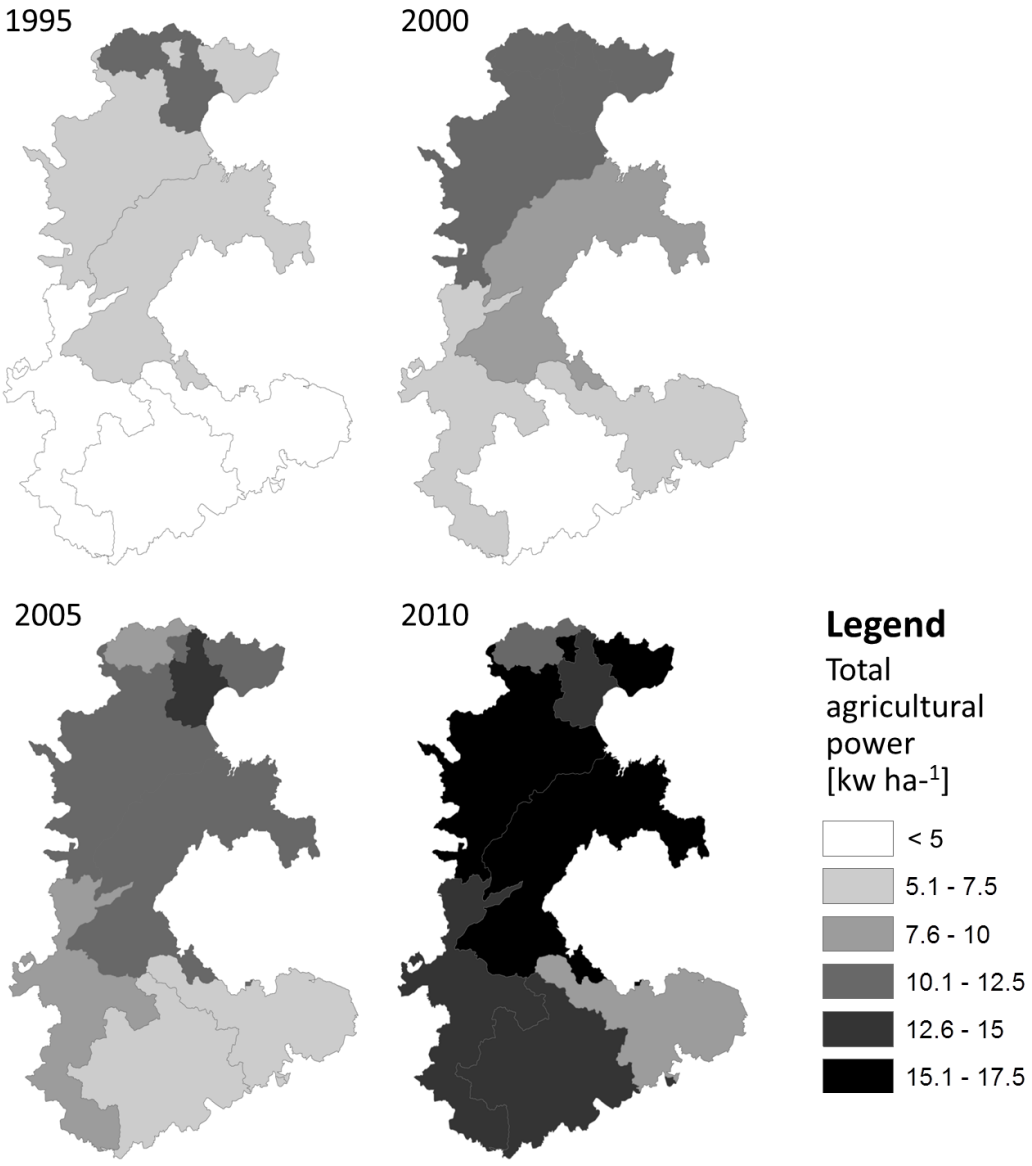
The combination of increasing labor cost and availability of capital, led to an acceleration of investments into farm machinery in the last 15 years. From 1995 to 2010 the available power of agricultural machinery per cultivated area increased from 5.6 kilowatt hectare^{-1} to 13.7 kilowatt hectare^{-1} in the NCP in average. Figure 4 shows the spatial variation of availability of farm machinery over the NCP. The southern provinces of Henan, Anhui and Jiangsu had the lowest levels of mechanization in 1995, while the provinces of Beijing and Tianjin already featured a relatively high

level at that time. Over the years, availability of machinery increased steadily in all provinces with the highest level of mechanization being reached in the provinces of Hebei and Shandong.

Table 1. Development of net income, wages and saving deposit in the NCP from 1995 to 2010 ([2,28–33]; compiled by authors).

Item	1995	2000	2005	2010
Net income of rural population (RMB capita^{-1} year^{-1})	1677	2500	3608	6603
Average wage of staff and workers (RMB person^{-1} year^{-1})	5202	9367	19146	40899
Savings deposit urban and rural areas (year-end) (RMB capita^{-1})	2568	5464	11188	23527

Figure 4. Development of total power of agricultural machinery per cultivated land over the seven provinces of the NCP from 1995 to 2010 ([2,28–33]; compiled by authors).



Looking in more detail on the mechanization level of the different steps of crop production, it becomes obvious that all parts of crop production undergo a shift towards increased use of farm machinery (Table 2). From 1995 until 2010, the area cultivated (tilled) by machinery increased from 43% to 58%, with the strongest increase in the last five years. The increases in area sown and harvested by machine are even higher, doubling in the last 15 years and reaching levels above 50% of total sown and harvested area in 2010. Regarding the use of mechanized plant protection, unfortunately only data from Jiangsu and Anhui was available. However, similar trends with mechanized sowing and harvesting were observed.

Table 2. Development of use of agricultural machinery in different crop production steps from 1995 until 2010 in the NCP ([2,28–33]; compiled by authors).

Item	Data sources (available provinces)	1995	2000	2005	2010
Cultivated area by machine (10000 ha)	Beijing, Tianjin, Hebei, Jiangsu, Anhui, Henan	1654	1900	1877	2346
as percentage of total sown area (%)		43	47	47	58
Sown area by machine (10000 ha)	Beijing, Tianjin, Hebei, Jiangsu, Anhui, Henan	910	1346	1608	2227
as percentage of total sown area (%)		24	34	40	55
Harvest area by machine (10000 ha)	Beijing, Hebei, Jiangsu, Anhui, Henan	1004	1250	1449	2005
as percentage of total harvest area (%)		27	32	36	50
Plant protection area by machine (10000 ha)	Jiangsu, Anhui	417	744	745	867
as percentage of total sown area (%)		26	44	44	52

When looking at the production factor land (Table 3), two points have to be differentiated: the development in total available arable land and the available arable land per farmer. Between 2000 and 2010 the total arable land resources in the seven provinces of the NCP remained fairly stable. However, after a strong increase until 2000, a strong decline is recorded until 2010. On the other side, with the labor force in the agricultural sector decreasing at an even higher pace, the cultivated land per person increased from 0.28 hectares in 1995 to 0.35 hectares in 2010.

Table 3. Development of total cultivated land, employment in agriculture and cultivated land per person in the seven provinces of the NCP from 1995 to until 2010 ([2,28–33]; compiled by authors).

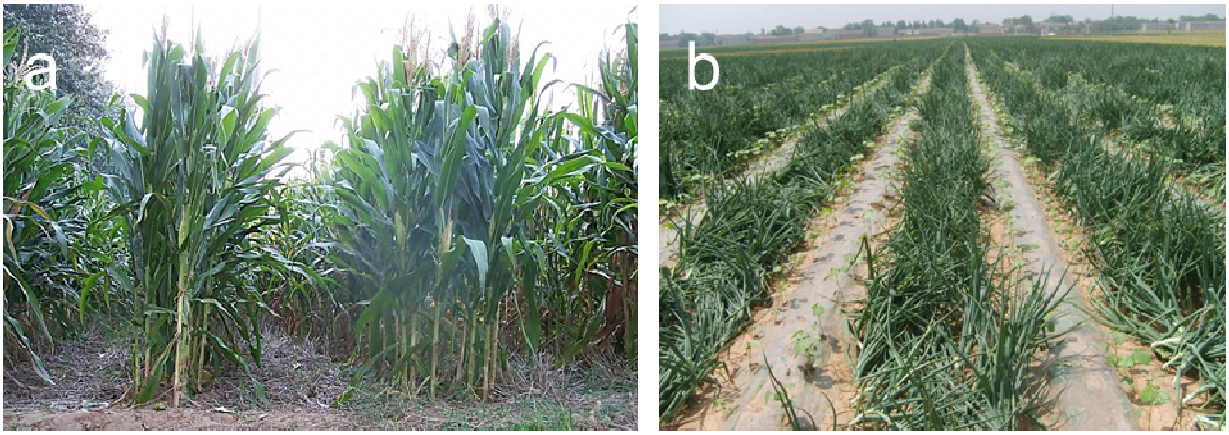
Item	1995	2000	2005	2010
Total cultivated land (1000 ha)	29584	34546 *	34546 *	30838
Employment in agriculture (10000 person)	10732	11395	9755	8748
Cultivated land per person (ha person^{-1})	0.28	0.30	0.35	0.35

* There was no land survey conducted between 2001 and 2005, which explains the same values in those two years.

3.2. What are Farmers' Motives to Practice Intercropping?

To understand the impact of the above-described socioeconomic and sociotechnical changes on intercropping systems, it is important to understand which kind of intercropping systems are practiced in the NCP. During the survey a huge variety of intercropping systems was identified in the region. Apart from various agroforestry systems, farmers practice pure cereal, cereal-legume, cereal-cotton, cereal-vegetable, cotton-legume, cotton-vegetable, legume-vegetable and pure vegetable systems. The systems are mainly relay intercropping systems, with one component crop being sown or planted into an already established crop. The two component crops only spend part of their growing period together in a field. For a better understanding of how this works, two common systems are illustrated (Figure 5). The winter wheat-maize intercropping system had been very popular in all provinces of the NCP in the past, and is still of some importance. The onion-cotton relay intercropping system is widely practiced in Feixiang county, Hebei province.

Figure 5. (**a**) Relay intercropping of maize and wheat in Shandong in September; (**b**) Relay intercropping of cotton and onion in Hebei in May.



In both presented intercropping systems, as well as in most other intercropping systems, farmers reported that their main reason to practice the system is to make full use of their limited land resources. Rural farmers in the NCP still cultivate less than half a hectare in average [1], and in the past most households solely depended on the income from agricultural activity. As a result of availability of abundant labor force in combination with scarce land resources, very complex intercropping systems which demand a huge input of manual labor evolved. These systems are characterized by a very high land productivity and small labor productivity.

Additionally, farmers report about reduced pest and disease pressure in their intercropping systems compared to monocropping. This not only saves input of pesticides, which reduces production cost and benefits the environment. Also, like in the case of chili-maize intercropping, dried chili of higher quality, which can fulfill export standards more easily, can be produced. To our surprise, the often mentioned advantage that intercropping can help to avoid the risk of crop failure (e.g. [34,35]) seems of no importance to Chinese farmers. We assume that the reliable supply of farm inputs, especially irrigation water, fertilizer and pesticides, already ensures high crop yields.

On the contrary, farmers complain that intercropping is very labor demanding, both in quantity and quality. Not only farmers have to spend more time in the field, but they have to manage a very sophisticated cropping system. Throughout the cropping season, management practices are more complex, like sowing or planting the second crop into an already established crop. The same holds true for the harvest of the crop which reaches maturity first. Here, farmers have to be very careful not to damage the remaining crop with the later harvest date. In most cases, the harvested good has to be transported manually to the field border and cannot be stored temporarily in the field.

The survey furthermore revealed that intercropping systems are more widespread in remote regions with limited off-farm income possibilities compared to suburban regions, where farmers already generate a great part of their income off-farm. In case of the winter wheat-maize relay intercropping system, rural farmers reported that, as the younger generation left the village to work as migrant workers in the bigger cities, the traditional system was given up. Labor resources were insufficient to maintain it. The developments of such pure cereal intercropping systems differ strongly from the developments of vegetable intercropping systems. Farmers and extensionists reported stable and even increasing areas of, for instance, onion-cotton, spinach-garlic and chili-maize intercropping in their region.

4. Discussion

4.1. How Do the Changing Socioeconomic Conditions Impact Intercropping Practices?

Most intercropping systems in the NCP are row intercropping systems with alternating rows of two different crops (Figure 5). These systems significantly out-yield their monocropping equivalents by a more efficient resource use, and, in the past, enabled farmers to make optimal use of their limited land resources. However, the trend analysis of the last 15 years revealed that labor resources are declining, and the land cultivated per person increased strongly. The continuously increasing incomes, employment opportunities in the non-agricultural sectors, and increasing labor cost, also in rural areas of the NCP, diminish the economic advantage of those high-yielding, but labor-intensive systems.

Moreover increasing incomes and accumulation of capital in rural households fostered the purchase of agricultural machinery and mechanization of agricultural production in the NCP. The observed tremendous increase in area with mechanized sowing, harvesting, and plant protection measures, has direct negative impact on intercropping practices. As most management steps in the traditional row intercropping systems cannot be conducted using machinery, agricultural mechanization and traditional row intercropping are incompatible.

This development is well displayed by the case of the formerly very popular winter wheat-maize relay intercropping system, which strongly lost importance in the NCP due to insufficient labor force, as reported by farmers. This also explains the strong decline in intercropping area in the NCP from the beginning of the 1990s [24] until today.

When looking at the impact of changing frame conditions on the different types of currently practiced intercropping systems in the NCP, one has to distinguish between systems that focus on cereal, legume and cotton production, and systems that include vegetables. Monocropping of cereals, legumes and cotton is characterized by a very high level of mechanization, while for the production of

vegetables still a lot of hand labor is required. Planting of vegetable seedlings and harvest of vegetable crops is mostly conducted by hand or semimechanized, even in high-tech agricultural systems. The higher monetary value that can be achieved by the production of vegetables justifies a high input of manual labor, even if it is expensive. This also affirms the findings of the survey, which revealed that the practice of vegetable intercropping systems in the NCP by far did not decline as much in the last years as cereal intercropping systems.

The major changes in frame conditions for farming and their impact on the practicing of intercropping by farmers in the past and in the future are given in Figure 6. All trends in production factor endowment are estimated to continue in the future. With the strong efforts of the Chinese government to develop the light industry sector [36] the available labor in the agricultural sector is likely to decline even more than in the past 15 years. Available capital is likely to continue to increase, though not in such an exponential manner. Available land resources are likely to decline slightly, due to loss to urbanization and infrastructure, as well as degradation of agricultural soils. Machine use is likely to increase further, with the upcoming reform of land use rights and land consolidation [37,38] working as a catalyst, justifying the investment into even larger machinery. Moreover, the Chinese government promotes the "accelerated development of modern agriculture" as a key target in its twelfth five-year plan [36], leading to further mechanization. However, as shown in the more developed regions of Beijing and Tianjin in the past, increase in mechanization of agriculture might also slow down slightly in the other parts of the NCP.

All the presented factors had a strong influence on the practicing of intercropping in the last 15 years, with a decline from about one third of total cultivated area to an estimated five percent according to our observations.

Figure 6. Summary of analyzed and estimated development of production factor endowment for farming in the last 15 years and upcoming ten years respectively, and its impact on practicing of intercropping systems in the NCP.

Production factor	1995 – 2010	2011 - 2020
Labor	- 18.5%	
Capital	+ 1001.0%	
Land	+ 4.2%	
Machine Use	+ 144.6%	
Intercropping	- 85.0%	?

The question that now needs to be answered is how to adjust the traditional intercropping systems to make them fit the demands of modern agriculture in the NCP. If intercropping systems should be maintained on a larger scale, immediate action is to be taken.

4.2. How to Adjust the Intercropping Systems to Fit the Demands of Modern Agriculture?

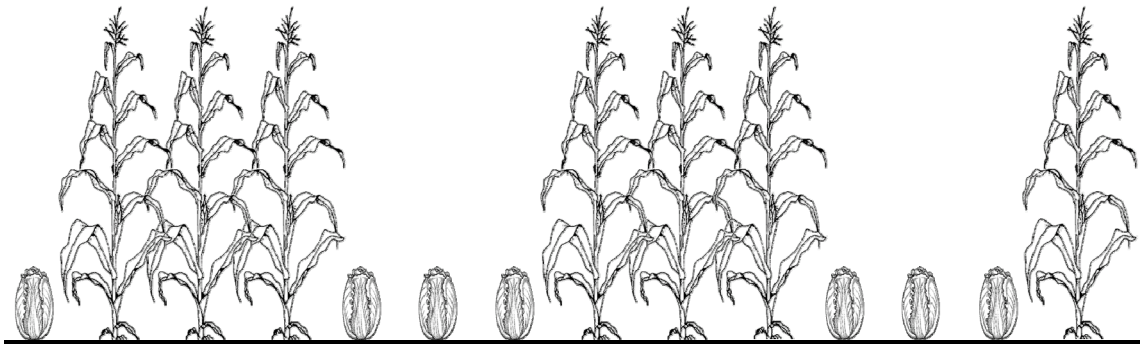
Two different pathways can be followed to adapt the traditional intercropping systems to future demands. Either the intercropping design has to be adjusted, so that at least part of the management practices can be accomplished by existing machines, or new machinery has to be developed that enables the mechanization of the traditional row systems.

4.2.1. Adjust the Intercropping System to the Existing Machinery

In certain intercropping systems, synergistic effects were observed up to a strip width of eight meters [39], while in other systems, positive effects already declined with strip widths of one meter [40]. Nowadays, the majority of farm machinery in China has a working width of less than two meters. Thus, depending on the crop combination, the conversion to mechanized strip systems seems an appropriate solution that can make use of synergisms between the two component crops (Figure 7). Optimizing the design of such a strip intercropping system according to local soil and climate conditions is essential to maximize resource capture, yields and economic profit. Among others factors for intercropping design are crop combination, sowing dates, strip widths, row spacing, and cultivar selection.

Figure 7. Illustration of **a)** the traditional row intercropping system and **b)** adjusted strip intercropping system; maize and Chinese cabbage are selected as demonstration crops

(**a**)

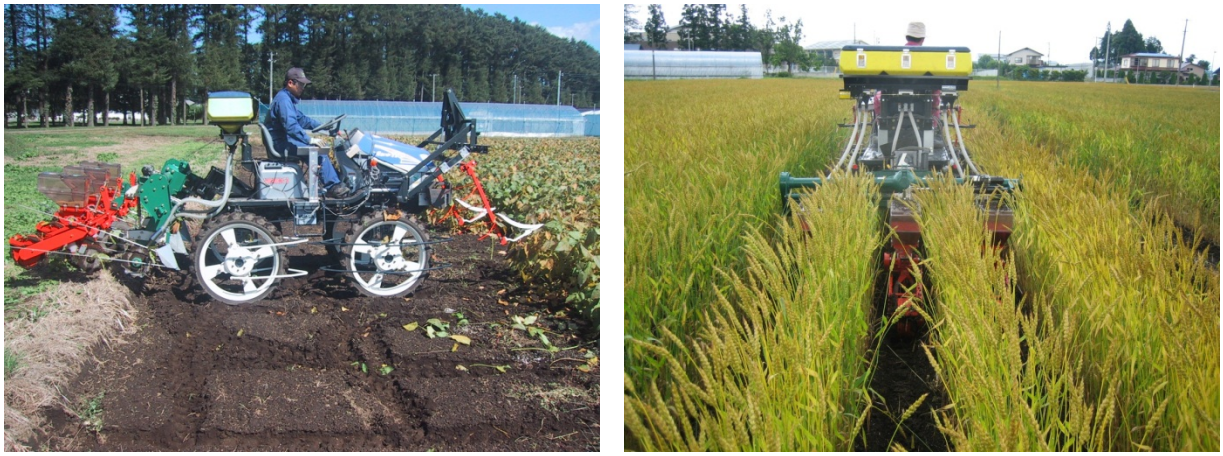


(**b**)

4.2.2. Adjust the Machinery to the Traditional Row-intercropping System

The second pathway, the adjustment of machinery to mechanize the traditional row intercropping systems, constitutes the most convenient solution to farmers, as they could maintain their traditional crop cultivation systems. Additionally all attributed advantages of row intercropping could be maintained, from yield advantage to environmental benefits. As the design of intercropping systems vary strongly worldwide, and even on regional scale in the NCP, there is hardly any commercial interest by agricultural engineering companies to research and develop such machinery. Up to now, only one case of development of specific intercropping machinery is reported in literature. The "Lowland Crop Rotation Research Team" at the "NARCT: NARO Agricultural Research Centre for Tohoku region" in Northern Japan developed a promising machine, called the "Interseeder" (Figure 8). It enables the sowing of wheat and soybean in a double-relay wheat-soybean row intercropping system. The newly developed seeder is a high clearance tractor which is equipped with three fertilizer and drill units [41]. However, seeding capacity is very limited and high development and production cost did not allow the "interseeder" to become a commercial success.

Figure 8. (**a**) Side view of the "interseeder", and (**b**) sowing of soybean into established wheat crop using the "interseeder" (Pictures courtesy: Kouichi Amaha, NARCT, Japan)



(**a**) (**b**)

4.2.3. Inter- and Trans-disciplinary Adjustment Process

For the development of successful intercropping systems for the local production conditions in the NCP, it will be essential that agronomists, crop simulation modelers and agricultural engineers work hand in hand with agricultural economists to not only develop a high yielding and resource-efficient system, but also ensure its profitability. Only if the yield advantage is able to even out the extra costs of additional management measures, will the system have any chance of being widely adapted. To test the economic sustainability of a certain system, sensitivity analysis should be conducted to test varying labor, input and output prices on the net profit of the system. Furthermore, the purchase price and maintenance cost of newly developed intercropping machinery has to be competitive with that of conventional machinery, or be compensated by the increased output achieved in an intercropping system compared to its monocropping equivalents.

Additionally, it is of great importance to integrate farmers' knowledge into the adjustment process [42,43]. There are infinite possibilities to arrange two companion crops in time and space. Up to now, no all-embracing approach could be developed that is able to be globally applicable to the complexity inherent in intercropping. When explaining the interactions among species, the results of most publications are valid for the tested crop combination under the environmental conditions of the experimental sites and years, the used cultivars, and all other management options included. Transferring the findings to other years, locations, and so on is much more ambiguous for intercrops compared to sole cropping. In this respect the role of farmers' knowledge becomes crucial.

5. Conclusion

Intercropping in the NCP has a strong potential to produce high yields in an environmentally friendly way. However, it strongly lost importance among cropping systems in the NCP in the last 20 years. With the change in frame conditions for farming continuing with the same speed, most intercropping systems which are still practiced nowadays are prone to extinction. The steadily declining labor force and the simultaneously increasing labor cost in rural China, continuously reduce the profitability of currently practiced intercropping systems. Additionally, the traditional row intercropping systems cannot get in line with the strongly increasing use of agricultural machinery, a result of available capital among the rural population in the NCP. Research has to offer solutions to farmers, if those potentially sustainable systems should be maintained. We recommend an integrative research approach to cope with the challenges involved. Whether the row-intercropping systems are transformed to strip-intercropping system, or new machinery is developed for mechanization of the traditional systems, agronomists, crop simulation modelers, agricultural engineers and agricultural economists need to work closely together. Additionally integration of farmers' knowledge into the development process is important, as only systems which convince farmers have the potential to be successfully distributed and adapted. Only the widespread practice of intercropping can finally give a significant contribution to the sustainable development of agricultural systems in the NCP.

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Conflict of Interest

The authors declare no conflict of interest.

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