A peer-reviewed version of this preprint was published in PeerJ on 26 June 2019.

View the peer-reviewed version (peerj.com/articles/6890), which is the preferred citable publication unless you specifically need to cite this preprint.

Yan Z, Li W, Yan T, Chang S, Hou F. 2019. Evaluation of energy balances and greenhouse gas emissions from different agricultural production systems in Minqin Oasis, China. PeerJ 7:e6890 https://doi.org/10.7717/peerj.6890
Evaluation of energy balances and greenhouse gas emissions from different agricultural production systems in Minqin Oasis, China

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Agricultural production in Minqin Oasis, China, is commonly categorized as intensive crop production (ICP), integrated crop-livestock production (ICLP), intensive livestock production (confined feeding) (IFLP), and extensive livestock production (grazing) (EGLP). The objectives of the present study were to use a life cycle assessment (LCA) to evaluate the on farm energy balances and greenhouse gas (GHG) emissions of agricultural production, and to compare the differences among the four systems. 529 farmers in eight towns of Minqin Oasis were selected to complete a face-to-face questionnaire. AVONA analysis of the average data from 2014 to 2015 indicated that the net energy ratio (Output/Input) for the EGLP system was significantly higher than for each of the other three systems (P < 0.01), whereas the differences among the other systems were not significant. However, the EGLP system generated lower CO$_2$-eq emissions per hectare of farmland than each of the three other systems (P < 0.01). Relating carbon economic efficiency to market values (Chinese currency, ¥) of agricultural products, indicated that the carbon economic efficiency (¥/kg CO$_2$-eq/farm) of the IFLP system was significantly greater than that of the three other systems (P < 0.01). The net energy ratios of alfalfa (4.01) and maize (2.63) were significantly higher than the corresponding data of the other crops (P < 0.01). All of the emission sources data for ICP, ICLP, IFLP, and EGLP, when related to the contribution of GHG emissions, showed fertilizer, enteric methane emissions, and plastic mulch, contributed the highest proportions of GHG emissions of all production categories. The path models showed that class of livestock was strongly linked to economic income. The direct effects and total effects of water use efficiency, via their positive influence on energy balances and GHG emissions were much stronger than those of other dependent variables. In conclusion, the present study provides benchmark information on the factors...
for energy balances and GHG emissions for agricultural production systems in northwestern China.
Evaluation of energy balances and greenhouse gas emissions from different agricultural production systems in Minqin Oasis, China

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Abstract

Agricultural production in Minqin Oasis, China, is commonly categorized as intensive crop production (ICP), integrated crop-livestock production (ICLP), intensive livestock production (confined feeding) (IFLP), and extensive livestock production (grazing) (EGLP). The objectives of the present study were to use a life cycle assessment (LCA) to evaluate the on farm energy balances and greenhouse gas (GHG) emissions of agricultural production, and to compare the differences among the four systems. 529 farmers in eight towns of Minqin Oasis were selected to complete a face-to-face questionnaire. AVONA analysis of the average data from 2014 to 2015 indicated that the net energy ratio (Output/Input) for the EGLP system was significantly higher than for each of the other three systems ($P < 0.01$), whereas the differences among the other systems were not significant. However, the EGLP system generated lower CO$_2$-eq emissions per hectare of farmland than each of the three other systems ($P < 0.01$). Relating carbon economic efficiency to market values (Chinese currency, ¥) of agricultural products, indicated that the carbon economic efficiency (¥/kg CO$_2$-eq/farm) of the IFLP system was significantly greater than that of the three other systems ($P < 0.01$). The net energy ratios of alfalfa (4.01) and maize (2.63) were significantly higher than the corresponding data of the other crops ($P < 0.01$). All of the emission sources data for ICP, ICLP, IFLP, and EGLP, when related to the contribution of GHG emissions, showed fertilizer, enteric methane emissions, and plastic mulch, contributed the highest proportions of GHG emissions of all production categories. The path models showed that class of livestock was strongly linked to economic income. The direct effects and total effects of water use efficiency, via their positive influence on energy balances and GHG emissions were
much stronger than those of other dependent variables. In conclusion, the present study provides benchmark information on the factors for energy balances and GHG emissions for agricultural production systems in northwestern China.

**Key words**: Minqin Oasis; Energy balances; Greenhouse gas emissions; Life cycle assessment.
1. Introduction

Energy is the driving force of existence and is required for agricultural production systems. Studies on energy and GHG emissions are key for analyzing the structure and function of agricultural production systems (Ren et al., 2009). Along with high levels of dependency on fuel energy and other energy resources, agricultural production has a major impact on GHG emissions, leading to serious environmental problems of which global warming and GHG emissions are considered to be important (Khoshnevisan et al., 2014), affecting the stability and sustainability of agricultural ecosystems, and consequently threatening global food security and ecological security. Agriculture is considered one of the most important global emitters of GHG (Cheng et al., 2011). With the population growth and the large food demand in China, the challenge of reducing GHG emissions is huge. The main sources of GHG emissions are the use of fertilizer and fossil fuel in crop production, and enteric methane and manure management in livestock production. The GHG emissions in China accounted for a large proportion of global emissions in 2014 (IPCC, 2014). Similar to other countries, the agricultural emissions mitigation policy in China faces a range of challenges due to the biophysical complexity and heterogeneity of farming systems, as well as other socioeconomic barriers (Wang et al., 2014). At present, the large population and food demand are the main challenges in China. With the rapid development of society, the change in the food structure, and the increase in the quantity of animal-derived food, GHG emissions will increase in China (Dong et al., 2008). Generally, there are three categories for studying energy balances and GHG emissions from global agricultural production (Hou et al., 2008), i.e., crop production, livestock production only, and the combination of crop
and livestock production. There is little information available on energy balances and GHG emissions in agricultural production systems in oases in arid regions of China based on production type. Arid regions cover ~ 40 % of the Earth’s land surface (Reichmann and Sala, 2015). Drying trends may occur most significantly in semi-arid and arid regions as a result of global warming (Huang et al., 2016). The mountain-oasis-desert coupling ecological system is widely distributed in inland areas of the world (Ren and Wan, 1994). Oasis and desert are the dominant ecological landscapes in arid regions of the world, in which water comes from rivers originating from high mountains. Agricultural production systems in Minqin Oasis surrounded by the Tengger and Badain Jeran Deserts vary greatly in different regions, mainly due to the distribution of water sources located in the Shiyang River, the geography, and other environmental conditions (He et al., 2004). The process and control of desertification in Minqin Oasis are principle modes of action in China and even the world (Hou et al., 2009). Over the past 2,000 years, agricultural production has relied on an extensive grazing system. In history, there are three periods of the opening up of grasslands for planting that resulted in soil desertification in Minqin Oasis. The succession order of agricultural systems in Minqin Oasis is extensive livestock production (grazing) (EGLP), integrated crop-livestock production (ICLP), and intensive crop production (ICP). Agricultural activities of Minqin Oasis, located in northwestern China, are commonly categorized into four contrasting systems: ICP, ICLP, intensive livestock production (confined feeding) (IFLP), and EGLP (Hou et al., 2009). The ICP and IFLP are practiced in well-watered centre of Minqin Oasis. The ICLP system is located close to the desert. Grazing in the EGLP system, which is located in the desert, is the main production mode (Figure
However, there is no information available on the net energy ratio and GHG emissions in Minqin Oasis. Therefore, the present study was designed to evaluate the effect of different agricultural production systems in Minqin Oasis on the net energy ratio, carbon economy efficiency, and GHG emissions. These data can offer key information for pursuing low-carbon agriculture and for adjusting the agricultural structure in northwestern China.

2. Materials and Methods

The present study was conducted to evaluate the energy balances and GHG emissions within the farm gate using the life cycle assessment (LCA) technique for four contrasting agricultural production systems in Minqin Oasis, China. The CH$_4$ and N$_2$O emission data were converted into CO$_2$ equivalents (CO$_2$-eq) using their Global Warming Potential (GWP), with GWP of 25 for CH$_4$ and 298 for N$_2$O (IPCC, 2006). The data used to calculate the GHG emissions were obtained from official records, farm survey data and published literature.

2.1. Agricultural production systems in Minqin Oasis

Minqin Oasis, located in northwestern China (103°05'E, 38°38'N), covers an area of 1.59×10$^6$ hectares (He et al., 2004). Minqin Oasis has a continental arid climate, and the mean annual temperature, annual frost-free days, and annual rainfall are 7.6°C, 175 d, and 110.7 mm, respectively. The mean annual rainfall and temperature over the 20-year period from 1997 showed respective decreasing and increasing trends (Figure 2). Shiyang River, which originates in Qilian Mountain, is the economic lifeblood of Minqin Oasis. The IFLP system has a rich underground water source upstream of Shiyang River for livestock production. However, two of
the systems, ICP and ICLP, mainly depend on irrigation, which enables a high input and output of crop production. There was no grazing in the ICLP, and all forage fed to livestock was maize, alfalfa hay and crop straw. Grazing and rangeland are the main production modes at the bottom of Shiyang River.

To facilitate a comparison of energy balances and GHG emissions from crop and livestock production among the four systems in Minqin Oasis, two typical towns were selected from each production mode to represent the average condition of agricultural production, namely, Caiqi and Chongxing for IFLP; Suwu and Daba for ICLP; Dongba and Shuangzike for ICP; and Hongshagang and Beishan for EGLP (Figure 1).

2.2. Data Collection

Data used in the present study were collected from farm surveys and published literature. The farm surveys were undertaken from 2014 to 2015 with data collected from 529 farmers using a face-to-face questionnaire method in the 8 towns selected for the present study (Table 1). Over 80% of farmers selected in 2014 were questioned again in 2015. The questionnaire was designed to collect information on crop and livestock production. The information collected for crop production included the following: crop type, sowing area for each crop, production of each crop, seed source and amount of seeds used, type and rate of fertilizers used in different growth periods, type and rate of pesticide used, fuel consumption for production (ploughing, tillage, transportation, harvesting and packaging), amount of plastic film, farm machine (type, life and working hours), electricity consumption for irrigation, yield of crop product, and yield of crop straw. There was no grazing in the ICLP system; forage fed to livestock was from maize and
alfalfa produced in crop production. The information for livestock production collected through the farm survey included the following: species, livestock population, age, weight, yields of carcass weight, milk and wool, feed resources and feed consumption. The price of farm products from 2014 to 2015 was obtained from a market survey (Table 2). The information for the structural equation model collected from public literature included the following: the distance from the oasis to the desert, the distance from the oasis to mountains, soil particle diameter, planting structure, breeding structure, water use efficiency, economic income, energy balances and carbon balances (carbon stock minus GHG emissions from agricultural production input).

2.3. Calculation of energy and GHG emissions from agricultural production

2.3.1. Energy balances of crop & livestock production

For agricultural production systems, the total energy inputs consumed are the human-applied energies classified as direct energy and indirect energy. The energy inputs of the crop production system were estimated using the following equation (1).

\[
EI_{\text{crop}} = \sum_{i=1}^{n} \left( AI_{i,j} \times EF_{i,j} + AI_{s,j} \times EF_{s,j} + AI_{f,j} \times EF_{f,j} + AI_{p,j} \times EF_{p,j} + AI_{ie,j} \times EF_{ie,j} + AI_{pm,j} \times EF_{pm,j} + AI_{dc,j} \times EF_{dc,j} + AI_{md,j} \times EF_{md,j} \right),
\]

where \( EI_{\text{crop}} \), \( i \), and \( n \) represent the energy inputs (MJ/farm), crop type \( i \), and number of crops /farm, respectively. \( AI \) represents farm inputs, and \( EF \) represents energy factors for the crop type \( i \): \( l \sim \) labor h/fm (male and female inputs with separate values (Nautiyal et al., 1998); \( s \sim \) seed kg/fm (energy required for seed cleaning and packaging); \( f \sim \) fertilizer kg/fm; \( p \sim \) pesticides kg/fm; \( ie \sim \) electricity for irrigation kW.h/fm (electricity used for on-farm pumping); \( pm \sim \) plastic film kg/fm (input fossil fuel energy required for manufacture, transport, packaging, and
use of fertilizer, pesticide, and mulch); dc ~ diesel fuel L/fm; md ~ machinery kg/fm (= manufacture energy + fuel consumption energy + depreciation energy) (Table 3). In the field, and the average lifetime of agricultural machinery is 15 years. In the EGLP system, there was no crops for the energy inputs.

The energy output of the crop refers to the energy density of that product including the grain, straw, and root. The energy outputs for each type of crop are calculated using equation (2).

\[ EO_{\text{crop}} = \sum_{i=1}^{n} (Y_{\text{grain,}i} \times EF_{\text{grain,}i} + Y_{\text{straw,}i} \times EF_{\text{straw,}i} + Y_{\text{root,}i} \times EF_{\text{root,}i}), \] (2)

where \( EO_{\text{crop,}i} \), \( i \), and \( n \) represent the energy outputs (MJ/farm), crop type \( i \), and number /crops, respectively. \( Y \) represents crop yield, and \( EF \) represents energy factors for the crop type \( i \): grain ~ crop grain kg/fm; straw ~ crop straw kg/fm; root ~ crop root kg/fm (Table 3).

For livestock production, input energies included feed production and processing, veterinary drug production and transfer, labor, electrify and fuel (electricity & coal) inputs for housing structures. The output energies were carcass, milk, and wool. The energy inputs for each category of livestock are calculated using equation (3).

\[ EI_{\text{livestock}} = \sum_{i=1}^{n} \left( \sum_{j=1}^{m} (FI_{\text{feed,}j} \times EF_{\text{feed,}j}) + DI_{\text{drug,}i} \times EF_{\text{drug,}i} + LI_{\text{labor,}i} \times EF_{\text{labor,}i} , \right. \]
\[ \left. + HMI_{\text{elec,}i} \times EF_{\text{elec,}i} + HMI_{\text{coal,}i} \times EF_{\text{coal,}i} \right) \] (3)

where \( EI_{\text{livestock,}i} \), \( i \), \( n \), \( j \), and \( m \) represent the energy inputs (MJ/farm), livestock category \( i \), number of livestocks /farm, feed type \( j \), and number of feeds /farm, respectively. \( FI_{\text{feed,}j} \) (kg/head), and \( EF_{\text{feed,}j} \) represent feed input classified as \( j \), and energy value of the feed classified as \( j \), respectively. \( DI_{\text{drug,}i} \), \( LI_{\text{labor,}i} \), \( HMI_{\text{elec,}i} \) and \( HMI_{\text{coal,}i} \) represent the energy input of livestock...
classified as i for veterinary drug production and processing (kg/head), human labor (h/head),
lighting of housing structures (kWh/head), and heating of housing structures in winter for
livestock management (kg/head), respectively. $EF_{drug,i}$, $EF_{labor,i}$, $EF_{elec,i}$ and $EF_{coal,i}$ represent the
energy factors of livestock classified as i for drug, labor, electricity and coal, respectively (Table
3). In the EGLP system, the energy input only included inputs of supplementary feeding in
winter.

The energy outputs for each category of livestock are calculated using equation (4).

$$
EO_{livestock} = \sum_{i=1}^{n} (Y_{carcass,i} \times EF_{carcass,i} + Y_{milk,i} \times EF_{milk,i} + Y_{wool,i} \times EF_{wool,i})
$$

(4)

where $EO_{livestock}$, i, and n represent energy output (MJ/farm), livestock category i, and number of
livestocks /farm, respectively. $Y$ represents the yield of livestock product, and $EF$ represents
energy factors for the livestock category i: carcass ~ livestock carcass kg /fm; milk ~ dairy milk
kg /fm; wool ~ sheep wool kg/fm (Table 3). Based on the energy balances of the inputs and
outputs, the energy balances and net energy ratio were calculated as follows.

$$
EB_{farm} = (EO_{crop} + EO_{livestock}) - (EI_{crop} + EI_{livestock})
$$

(5)

$$
NER_{farm} = \frac{EO_{crop} + EO_{livestock}}{EI_{crop} + EI_{livestock}}
$$

(6)

where $EB_{farm}$, and $NER_{farm}$ represent the respective energy balances (MJ/farm) and the net energy
ratio (Output/Input) of agricultural production systems in Minqin Oasis. $EO_{crop}$, $EO_{livestock}$, $EI_{crop}$,
and $EI_{livestock}$ represent the same parameters as in the previous equations.

2.3.2. GHG emissions from crop production and rangeland

The GHG emissions from crop production and pasture (rangeland) using the LCA technique
were estimated using the following equation (7).

\[
CE_{crop\&rangeland} = \sum_{i=1}^{n} (EI_{crop\&rangeland,i} \times EF_{l,i} + AI_{l,i} + AI_{s,i} + EF_{f,i} + AI_{f,i} \times EF_{f,i} + AI_{p,i} \times EF_{p,i} + AI_{ie,i} \times EF_{ie,i} + AI_{pm,i} \times EF_{pm,i} + AI_{dc,i} \times EF_{dc,i} + AI_{md,i} \times EF_{md,i} + SOIL_{res,i}),
\]

(7)

where \(EI_{crop\&rangeland,i}\), \(i\), and \(n\) represent GHG emissions from crop production and pasture (kg CO\(_2\)-eq/farm), crop type \(i\), and number of crops /farm, respectively. \(AI\) represents farm inputs, and \(EF\) represents emission factors for the crop type \(i\): \(l\) ~ labor h/fm (male and female inputs with separate values); \(s\) ~ seed kg /fm (GHG emissions from seed cleaning and packaging); \(f\) ~ fertilizer kg/fm; \(p\) ~ pesticides kg/fm; \(ie\) ~ electricity for irrigation kW.h/fm (GHG emissions from electricity used for on-farm pumping); \(pm\) ~ plastic film kg/fm (GHG emissions from manufacture, transport, packaging, and use of fertilizer, pesticide, and mulch); \(dc\) ~ diesel fuel L/fm; \(md\) ~ machinery kg /fm (= GHG emissions from machinery manufacture + fuel consumption + machinery depreciation) (Table 3). In the field, the average lifetime of agricultural machinery is 15 years. The value of the emission factor for the above production input was calculated in the same way as the energy factor. \(SOIL_{res}\) only represents GHG emissions from soil respiration using the following equation (8) (Chen et al., 2010). For the EGLP system, GHG emissions from soil have been listed under crop and rangeland (Table 6), and are calculated for soil respiration only.

\[
SOIL_{res} = 1.55 \times e^{0.031 \times T} \times \frac{P \times SOC}{(P + 0.68) \times (P + 2.23)}
\]

(8)

where \(SOIL_{res}\), \(T\), \(P\), and \(SOC\) represent GHG emissions of heterotrophic respiration from the soil, the mean annual temperature, the annual rainfall, and organic carbon values of soil at a depth
between 0 and 20 cm, respectively.

The carbon stock of both crop and pasture (rangeland) refers to the carbon stock expressed as CO$_2$-eq, which is the net accumulation of photosynthetic products. The carbon stock of both crop and pasture is calculated using equation (9) (Shi et al., 2011b).

$$CS_{crop\&rangeland} = \sum_{i=1}^{n} (CS_{grain,i} + CS_{stem,i} + CS_{root,i}),$$  \hspace{1cm} (9)

where $CS_{crop\&rangeland}$, $i$, $n$, $CS_{grain,i}$, $CS_{stem,i}$, and $CS_{root,i}$ represent the carbon values (kg CO$_2$-eq/farm) accumulated in the plant (crop & grass) and soil in the process of plant (crop & grass) production, plant (crop & grass) type $i$, number of plants (crop & grass) /farm, grain of plant (crop & grass) type $i$, stem of plant (crop & grass) type $i$, and root of plant (crop & grass) type $i$, respectively. The values of $CS_{grain}$, $CS_{stem}$, and $CS_{root}$ were calculated using equations (10), (11) and (12) (Shi et al., 2011b). In order to evaluate the allocation of carbon to plant parts in the grain crop, the carbon concentration of all plants parts was assumed to be 0.45 g.g$^{-1}$.

$$CS_{grain} = \sum_{i=1}^{n} Yield_{i} \times (1 - WC_{i}) \times 0.45,$$  \hspace{1cm} (10)

$$CS_{stem} = \sum_{i=1}^{n} (CS_{grain,i} / H_{i} - CS_{grain,i}),$$  \hspace{1cm} (11)

$$CS_{root} = \sum_{i=1}^{n} (CS_{grain,i} + CS_{stem,i}) \times R_{i},$$  \hspace{1cm} (12)

where $CS_{grain}$, $CS_{stem}$, $CS_{root}$, $Yield_{i}$, $WC_{i}$, $CS_{grain,i}$, $CS_{stem,i}$, $H_{i}$, $R_{i}$, $i$, and $n$ represent the carbon stock of the plant (crop & grass) grain (kg CO$_2$-eq /kg grain), the carbon stock of the plant (crop & grass) stem (kg CO$_2$-eq /kg stem), the carbon stock of the plant (crop & grass) root (kg CO$_2$-eq /kg root), the yield of the plant classified as $i$ (kg /farm), the water content of the plant classified as $i$ (%), the carbon stock of the plant grain classified as $i$ (kg CO$_2$-eq /kg grain), the carbon stock
of the plant stem classified as \( i \) (kg CO\(_2\)-eq/kg stem), the harvest index of the plant classified as \( i \) (\%), the root-shoot ratio classified as \( i \) (\%), plant type \( i \), and number of plants classified as \( i \) (Table 4).

The carbon balances of crop production are calculated using equation (13).

\[
CB_{\text{crop\&rangeland}} = CS_{\text{crop\&rangeland}} - CE_{\text{crop\&rangeland}} \tag{13}
\]

where \( CB_{\text{crop\&rangeland}} \), \( CS_{\text{crop\&rangeland}} \), and \( CE_{\text{crop\&rangeland}} \) represent the respective carbon balances (kg CO\(_2\)-eq/farm), carbon stocks and GHG emissions of input of crop production and pasture. If the value of \( CB_{\text{crop\&rangeland}} \) is greater than zero, the agricultural production system is a carbon sink.

2.3.3. GHG emissions from livestock production

Annual GHG emissions from inputs for each class of livestock were calculated from four sources: feed production, feed processing, enteric fermentation, and manure management, using equation (14).

\[
CE_{\text{livestock}} = \sum_{i=1}^{n} \left( TC_2O_{\text{feed},i} + TC_2O_{\text{drug},i} + TC_2O_{\text{labor},i} + TC_2O_{\text{elec},i} + TC_2O_{\text{coal},i} + \right. \\
+ \left. TCH_4_{\text{Enteric},i} + TCH_4_{\text{Manure},i} + TN_2O_{\text{Manure},i} \right)
\]

where \( CE_{\text{livestock}} \), \( i \), and \( n \) represent the total GHG emissions of livestock (kg CO\(_2\)-eq/farm), the category of livestock, and livestock numbers classified as \( i \), respectively. \( TC_2O_{\text{feed},i} \), \( TC_2O_{\text{drug},i} \), \( TC_2O_{\text{labor},i} \), \( TC_2O_{\text{elec},i} \), \( TC_2O_{\text{coal},i} \), \( TCH_4_{\text{Enteric},i} \), \( TCH_4_{\text{Manure},i} \), \( TN_2O_{\text{Manure},i} \) represent the GHG emissions (kg CO\(_2\)-eq/farm) from feed production, feed processing, veterinary drug production and processing (kg CO\(_2\)-eq/farm), labor inputs (h/farm), lighting of the housing structure (kwh/farm), heating of the housing structure in winter (kg/farm), ruminant enteric fermentation...
The carbon stock (accumulation) of livestock production mainly included carbon stock expressed as CO\(_2\)-eq from livestock products, such as the carcass, milk and wool. The carbon stock of livestock is calculated using equation (15) (Wu et al., 2017).

\[
CS_{livestock} = \sum_{i=1}^{n} CS_{i} = \sum_{i=1}^{n} (LW_{i} \times 0.2),
\]

where \(CS_{livestock}\), \(i\), \(n\), \(CS_{i}\), and \(CW_{j}\) represent the carbon stock (kg CO\(_2\)-eq/farm), the category of livestock, livestock numbers classified as \(i\), carbon stock of livestock classified as \(i\), and live weight of livestock numbers classified as \(i\).

Carbon balances of livestock production are calculated using equation (16).

\[
CB_{livestock} = CS_{livestock} - CE_{livestock},
\]

where \(CB_{livestock}\), \(CS_{livestock}\), and \(CE_{livestock}\) represent carbon balances (kg CO\(_2\)-eq/farm), carbon stock (kg CO\(_2\)-eq/farm) and GHG emissions (kg CO\(_2\)-eq/farm) of livestock production input, respectively. If the value of \(CB_{livestock}\) is less than zero, the livestock production system is a carbon source. For the EGLP system, GHG emissions from soil have been listed under crop and rangeland (Table 6), and are calculated for soil respiration only.

**2.3.4. Carbon balances of agricultural production systems**

In brief, carbon balances of agricultural production systems in Minqin Oasis are calculated using equation (17).

\[
CB_{farm} = (CS_{crop\&rangeland} + CS_{livestock}) - (CE_{crop\&rangeland} + CE_{livestock}),
\]

where \(CB_{farm}\) represents carbon balances (kg CO\(_2\)-eq/farm) of agricultural production systems in
Minqin Oasis. $CS_{\text{crop&rangeland}}, CS_{\text{livestock}}, CE_{\text{crop&rangeland}},$ and $CE_{\text{livestock}}$ represent the same parameters as in the above equations. Values of $CB_{\text{farm}}$ greater than zero, equal to zero, and less than zero indicate that the agricultural production system is a carbon source, has a balanced carbon status or is a carbon sink, respectively.

2.3.5. Calculation of carbon economic efficiency

The total carbon economic efficiency (¥, Chinese currency) associated with emissions of one kilogram of carbon from crop or livestock products was calculated using equation (18) (Shi et al., 2011b).

$$CEE_{farm} = \frac{\sum_{i=1}^{n} (YP_{product(i)} \times PRICE_{product(i)})}{CE_{\text{crop}} + CE_{\text{livestock}}}.$$ (18)

where $CEE_{farm}$, $YP_{product(i)}$, $PRICE_{product(i)}$, and $i$ represent the carbon economic efficiency (¥/kg CO$_2$-eq), yield of products (kg), price of products (¥), and product category, respectively. $CE_{\text{crop}}$ and $CE_{\text{livestock}}$ represent the same parameters as in the above equations. All prices of products were based on the mean market price of these products in 2014 and 2015.

2.4. Statistical analyses

The statistical programme used in the present research was Genstat16.0 (16th edition; VSN International Ltd, UK). The differences in energy balances, carbon stocks, GHG emissions, carbon economic efficiency, net energy ratio, and net income were analysed using Linear Models, with the four kinds of agricultural production systems fitted as the fixed effect and other parameters as random effects. Predicted means, the standard error of the differences, and the level of significant differences were calculated using an internal algorithm. The temporal
variations in output indicators among the four systems were also evaluated using a chart presentation. Data that exhibited high heterogeneity of variance among treatments were transformed to ensure homogeneity of variance.

3. Results

3.1. Energy balance and net energy ratio of agricultural production

Energy balances and net energy ratios (NER) are presented in Table 5. For livestock production, input energy and output energy from IFLP were the highest among all four production systems; however, the net energy ratio (0.63 GJ/farm) for IFLP was the lowest among the three livestock production systems. Of all agriculture production systems in Minqin Oasis, EGLP had the lowest input energy (27.6 GJ/farm). In contrast, the net energy ratio (2.74) of the EGLP system was the highest of all four production systems. There were significant differences in energy balances and GHG emissions associated with crop production in Minqin Oasis. The net energy ratio of alfalfa (4.01) and maize (2.63) was significantly higher than the corresponding data for other crops (P<0.01) (Table 7).

3.2. GHG emissions from agricultural production

GHG emissions from production input, carbon stocks, and carbon balances of agricultural production systems, per farm (livestock or mixed), and per hectare (farmland), are presented in Table 6. GHG emissions (9,980.0 tonne CO$_2$-eq/farm) from the EGLP system were significantly higher than from each of the three other systems (P<0.05), but there were no significant differences between ICP and ICLP. Carbon stock (39,400.0 kg CO$_2$-eq/farm), and carbon balance (29,541.0 kg CO$_2$-eq/farm) in the EGLP system were significantly higher than in each of
the three other systems ($P<0.05$), but there were no significant differences in the three other production systems. At the cropland level, GHG emissions (5.6 tonne CO$_2$-eq/ha) in EGLP were significantly lower than in ICP and ICLP ($P<0.05$), but there were no significant differences between ICP and ICLP. The carbon stock (22.2 tonne CO$_2$-eq/ha) and carbon balances (16.6 tonne CO$_2$-eq/ha) in the EGLP system were significantly higher than in ICP and ICLP ($P<0.01$). The value of the carbon stock in ICLP was higher than the corresponding data from the ICP system ($P<0.05$).

Figure 3 shows the contribution of GHG emissions from agricultural production systems in Minqin Oasis. The GHG emissions caused by soil respiration accounted for a relatively large proportion of total GHG emissions in crop production; the contribution ratios being ICP: 41.85%, ICLP: 25.86% and EGLP: 99.31%. In the ICP system, fertilizer and mulch resulted in GHG emissions that accounted for 35.78% and 9.53%, respectively. In the ICLP system, methane emissions and fertilizer from enteric fermentation resulted in GHG emissions that accounted for 25.7% and 20.94%, respectively. In the IFLP and EGLP systems, methane emissions and N$_2$O emissions accounted for the greater proportion of total GHG emissions; the respective values being as follows:

IFLP ~ CH$_4$: 66.96%; N$_2$O: 30.78%; EGLP ~ CH$_4$: 0.42%; N$_2$O: 0.21% (Figure 3).

3.3. Carbon economic efficiency of agricultural production

The carbon economic efficiency of agricultural production in Minqin Oasis is presented in Table 6. That for IFLP was significantly higher than for each of the other three systems ($P<0.05$), whereas the differences among the other systems were not significant.
3.4. Net income of agricultural production

The net income of agricultural production in Minqin Oasis is presented in Table 5. Net income for IFLP (46,400 CN¥) was the highest among the four production systems. There were significant differences in net income between the three other production systems, as follows — EGLP: 39,100 CN¥; ICLP: 32,000 CN¥; ICP: 24,700 CN¥.

3.5. Analysis of structural equation model to identify the effects between dependent variables and predictor variables

The effects between dependent variables and predictor variables were presented in Table 8. The path models showed that class of livestock was strongly linked to economic income (Fig.4-a, Total effects = 0.769; Fig.4-d, Total effects = 0.762). The direct and total effects of water use efficiency on predicted variables (energy balances, carbon balances) were much stronger than on other dependent variables (Fig.4-b, Fig.4-c). Similarly, in path analyses, including the distance from the oasis to mountains as the exogenous variable, direct and total effects of water use efficiency (through its positive influence on energy and carbon balances), were much stronger than those of other dependent variables (Fig.4-e, Total effects=1.064; Fig.4-f, Total effects=1.144).

4. Discussion

4.1. Energy balance and net energy ratio of agricultural production systems

The energy balance of agricultural production systems can be influenced by variations in farm input and output capacities, including family population, production systems, environmental conditions, management regimes, and input capacity. The present carbon balances for
agricultural production are comparable to those published elsewhere. For example, Our net energy ratio for wheat and maize production are similar to those in Iran (2.08 vs. 2.13, 2.63 vs. 2.67, respectively) (Khoshroo, 2014; Yousefi et al., 2014). However, our input energy and output energy of maize production (76.5 and 201.0 GJ/ha, respectively) are much higher than those (50.5 and 134.9 GJ/ha, respectively) estimated using LCA in Iran (Yousefi et al., 2014). Our input energy for cotton production (51.0 GJ/ha) is much higher than that (31.2 GJ/ha) in Iran (Pishgarkomleh et al., 2012).

The nature of agricultural production systems is the flow and circulation of matter and energy (Sere et al., 1996). Energy is the foundation of the development of agricultural systems. Intensive crop production, which is an open system in Minqin Oasis, depends on high input that accounts for 99%, such as fertilizer, plastic mulch, and machinery. With the rapid development of industry, large inputs of inorganic energy can improve the living standard of local farmers, this can also impact local environment, especially with respect to modern inorganic energy, such as fertilizer, pesticide, plastic mulch, and so on. It is a sustainable mode of agricultural development to enlarge the alfalfa planting area and to breed numerous sheep in Minqin Oasis.

4.2. Carbon balances of agricultural production systems

As indicated previously, our GHG emission factors are comparable to those published elsewhere. For example, the average value of the carbon balance for grassland from intensive livestock production (Grazing) in Minqin Oasis is higher than that (49.1 vs. 22-44 g C/ m².year) for grassland in southern Belgium (Goidts and Wesemael, 2007), and lower than that (129 g C/m².year) for grazed European grassland. Our carbon emission for maize production (12,710
kg CO\textsubscript{2} eq/ha) is similar to that (12,865 kg CO\textsubscript{2} eq ha\textsuperscript{-1}) reported for Iran (Soussana et al., 2010). Similar findings were reported, i.e., that the restoration and reconstruction of grassland can significantly increase the amount of soil organic carbon storage in China (Li et al., 2006). The present carbon economic efficiency (¥1.79 /kg CO\textsubscript{2}-eq) is marginally above the high end of the range for wheat production ($0.085 /kg CO\textsubscript{2}-eq) in the USA (Twomey Sanders and Webber, 2014). The difference could, however, be partially attributed to the methodology used, which accounted for cultivation, processing, transport, storage, and end-use preparation for wheat production (Twomey Sanders and Webber, 2014).

There is no similar research on carbon balances, which are of great significance to adjust the structure of agricultural production in China. The high inputs, such as fertilizer, mulch and machining, accounted for a relatively large proportion, and low outputs in crop production resulted in high carbon emission in Minqin Oasis. In addition, GHG emissions might be assigned a price in prospective climate policy frameworks. It would be useful to know the extent to which those policies would increase the incremental production costs of crop production within the agricultural production system.

### 4.3. Uncertainty of GHG emissions assessment

Many factors could contribute to the uncertainty of the present assessment of GHG emissions from typical agricultural production systems in Minqin Oasis. First, although the eight towns selected from each production system were typical of the production system in the region, these eight towns might not fully cover all variations in crop and livestock production systems within each region. Second, the official data collection system in China might not be as good as
that in developed countries (Xue et al., 2014). In addition, the emission factors of the seed, P and K fertilizers, and pesticides in China were estimated using reported values (Cheng et al., 2011) and (Zeng et al., 2012), which originated from other countries. The use of the Tier 1 method proposed by the Intergovernmental Panel on Climate Change (IPCC) 2006 (IPCC, 2006) also added uncertainty to the present emission factors for livestock production because this method does not consider the effects of animals and dietary factors on enteric methane emissions. In summary, although the above uncertainties might add errors to estimates of GHG emissions in Minqin Oasis, our results could provide benchmark information for the Chinese government to develop appropriate policies to reduce GHG emissions from agricultural production in northwestern China. However, further improvement is required in future to upgrade the current evaluation of GHG emissions from agricultural production systems in this area.

5. Conclusions

The present study developed models to estimate energy balances and GHG emissions within the farm gate associated with the production per farm for the four contrasting agricultural production systems in Minqin Oasis. The statistical analysis of data from 2014 to 2015 indicated that the net energy ratio in EGLP was significantly higher than that in the three other systems. The current research found that the EGLP system in Minqin Oasis is a carbon sink, and the net income in IFLP was the highest among the four systems in Minqin Oasis. However, relative to the contribution of GHG emissions from production input, all of the results of the four agricultural systems showed that fertilizer, methane emissions from enteric fermentation, and plastic mulch
accounted for the greatest proportion. The path models showed that breeding structure was strongly linked to the economic income. The direct and total effects of water use efficiency via its positive influences on energy balances and GHG emissions were much stronger than those of other dependent variables. Although there is a range of uncertainties relating to the calculations of these emission factors, these data could provide benchmark information for Chinese authorities to evaluate the effect of GHG emissions from contrasting agricultural production systems in Minqin Oasis.

Acknowledgements

This research was co-funded by the National Natural Science Foundation of China (No.31660347&31172249), National Key Project of Scientific and Technical Supporting Programmes (2014CB138706) and Programme for Changjiang Scholars and Innovative Research Team in University (IRT13019).
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Figure 1

Satellite map of study site in Minqin, China.
Figure 2

Annual mean temperature and rainfall from 1997 to 2017.
Figure 3

Contribution of emission sources of ICP, ICLP, IFLP, and EGLP.

MM, manure management; EF, enteric fermentation.
Figure 4

Path models showing direct and indirect effects of predictor variables on farm net income, energy balance, and carbon balances.

The path models with significant correlation are presented as solid lines. The values on solid lines represent standardized regression weights. Interrupted lines indicate no significant correlation between two variables. Black arrows indicate positive effects. For each endogenous variable the relative amount of explained variance is given. For meanings of abbreviations of variables in oval boxes, see Table 8. $\chi^2$: chi-square. p: probability level. df: degrees of freedom. n: sample size.
Table 1 (on next page)

Data on cropland and livestock in farms at the research sites.
Table 1 Data on cropland and livestock in farms at the research sites.

|                     | ICP  | ICLP | IFLP | EGLP |
|---------------------|------|------|------|------|
| No. of farm surveys | 164  | 176  | 126  | 63   |
| No. of people/household | 4-6 | 4-6 | 4-6 | 4-6 |
| Cropland (ha/farm)   |      |      |      |      |
| Wheat (Spring)       | 0.067-0.133 | 0.067-0.100 | -    | -    |
| Maize               | 0.100-0.133 | 0.133-0.200 | -    | -    |
| Cotton              | 0.133-0.200 | 0.133-0.200 | -    | -    |
| Sunflower           | 0.133-0.200 | 0.133-2.500 | -    | -    |
| Alfalfa             | 0.050-0.067 | 0.067-0.167 | -    | -    |
| Chili               | 0.000-0.033 | -        | -    | -    |
| Tomato              | 0.000-0.067 | 0.000-0.067 | -    | -    |
| Melon               | 0.033-0.067 | 0.000-0.033 | -    | -    |
| Rangeland (ha/farm)  | -    | -    | -    | 1350-1900 |
| Livestock (sheep units\$/farm) |      |      |      |      |
| Sheep               | -    | 20-40 | 785-880 | 330-349 |
| Dairy cattle        | -    | -    | 200-250 | -    |
| Beef cattle         | -    | -    | 230-275 | -    |

1 sheep: 1.0 sheep unit (SU); dairy cattle: 4.5 SU; beef cattle: 4.0 SU.
Table 2 (on next page)

Average market price of inputs and outputs for agricultural production (2014 - 2015).
Table 2 Average market price of inputs and outputs for agricultural production (2014 - 2015).

| Input                                | Price (¥/kg) | Output                                | Price (¥/kg) |
|--------------------------------------|--------------|---------------------------------------|--------------|
| Seeds (¥/kg)                         |              | Crop products (¥/kg)                  |              |
| Wheat (spring)                       | 2.80         | Wheat (spring)                        | 0.75         |
| Maize                                | 16.00        | Maize                                 | 1.90         |
| Cotton                               | 6.80         | Cotton                                | 6.00         |
| Sunflower Seed                       | 48.00        | Sunflower Seed                        | 5.60         |
| Chili                                | 8.00         | Chili                                 | 1.30         |
| Tomato                               | 20.00        | Tomato                                | 3.00         |
| Melon                                | 16.00        | Melon                                 | 10.00        |
| Alfalfa                              | 40.00        | Wheat straw                           | 0.70         |
| Fertilizers (¥/kg)                   |              | Corn straw                            | 1.96         |
| Urea                                 | 2.00         | Alfalfa straw                         | 1.50         |
| Mono ammonium phosphate              | 2.60         | Livestock products (¥/kg)              |              |
| Phosphate fertilizers                | 0.50         | Lamb                                  | 38.00        |
| Compound fertilizers                 | 1.60         | Beef                                  | 60.00        |
| Potassium                            | 2.00         | Milk                                  | 4.00         |
| Manure                               | 1.00         | Wool                                  | 650.00       |
| Pesticide (¥/kg)                     |              |                                       |              |
| Herbicides                           | 28.00        |                                       |              |
| Insecticides                         | 22.00        |                                       |              |
| Fungicides                           | 25.00        |                                       |              |
| Mulch (¥/kg)                         | 0.77         |                                       |              |
| Fuel (¥/kg)                          | 12.86        |                                       |              |
| Electricity (¥/kwh)                  | 0.80         |                                       |              |
| Feedstuff (¥/kg)                     |              |                                       |              |
| Wheat straw                          | 0.70         |                                       |              |
| Corn straw                           | 1.96         |                                       |              |
| Alfalfa straw                        | 1.50         |                                       |              |
| Corn                                 | 1.96         |                                       |              |
| Soybean                              | 4.53         |                                       |              |
|               |       |
|---------------|-------|
| Wheat husk    | 1.67  |
| Veterinary vaccine (¥/dose) |     |
| Sheep         | 0.20  |
| Cattle        | 1.30  |
Table 3 (on next page)

Factors used for calculation of GHG emissions, energy inputs, and energy outputs.
Table 3 Factors used for calculation of GHG emissions, energy inputs, and energy outputs.

| Item | Sub-item | Factors | References |
|------|----------|---------|------------|
| **Emission factors of GHG for agricultural production** | Wheat (Spring) | 0.477 | (West and Marland, 2002) |
| | Maize | 3.85 | (Shi et al., 2011a) |
| | Cotton | 2.383 | (West and Marland, 2002) |
| | Sunflower | 0.47 | (Iriarte and Villalobos, 2013) |
| | Alfalfa | 9.643 | (West and Marland, 2002) |
| | Tomato | 1.63 | (Blook et al., 2010) |
| | Chili | 2.5 | the mean of other crops |
| | Melon | 1.9 | the mean of other crops |
| | N | 6.38 | (Lu et al., 2008) |
| | P | 0.733 | (Dubey and Lal, 2009) |
| | K | 0.55 | (Dubey and Lal, 2009) |
| | Soil emissions CO$_2$ after N application | 0.633 | (IPCC, 2006) |
| | Soil emissions N$_2$O after N application | 6.205 | (Adom et al., 2012) |
| | Herbicides | 23.1 | (Lal, 2004) |
| | Insecticides | 18.7 | (Lal, 2004) |
| | Fungicides | 13.933 | (Lal, 2010) |
| | Plastic mulch | 18.993 | (Cheng et al., 2011) |
| | Electricity for irrigation | 0.917 | (Shi et al., 2011a) |
| | Diesel | 2.629 | (Cheng et al., 2011) |
| | Fire coal | 2.763 | (Li et al., 2013) |
| | Steel | 2.309 | (Liu et al., 2016) |
| Machinery depreciation (kg CO\(_2\)-eq/year) | Tractor 7810 | 14.07 | (Dyer and Desjardins, 2006) |
|--------------------------------------------|--------------|-------|----------------------------|
|                                           | Tractor 55/60 | 0.49  | (Dyer and Desjardins, 2006) |
|                                           | Tractor1002/1202 | 1.32 | (Dyer and Desjardins, 2006) |
|                                           | Tractor 250 | 0.16  | (Dyer and Desjardins, 2006) |
|                                           | Harvester1200 | 0.66  | (Dyer and Desjardins, 2006) |
|                                           | Harvester154 | 1.34  | (Dyer and Desjardins, 2006) |
| Labor (kg CO\(_2\)-eq/hour)               | Labor         | 0.115 | (Stocker and eds., 2014) |
|                                           | Maize         | 0.0102 | (Meng et al., 2014) |
|                                           | Soybean       | 0.1013 | (Meng et al., 2014) |
|                                           | Wheat         | 0.0319 | (Meng et al., 2014) |
| Feed processing (kg CO\(_2\)-eq/kg)       | Sheep         | 125   | (IPCC, 2014) |
|                                           | Beef cattle   | 1175  | (IPCC, 2014) |
|                                           | Dairy cattle  | 1525  | (IPCC, 2014) |
| CH\(_4\) emissions from enteric fermentation (kg CO\(_2\)-eq/head/year) | Sheep | 2.75 | (IPCC, 2014) |
|                                           | Beef cattle   | 25    | (IPCC, 2014) |
|                                           | Dairy cattle  | 250   | (IPCC, 2014) |
| CH\(_4\) emissions from manure management (kg CO\(_2\)-eq/head/year) | Beef cattle | 120.4 | (IPCC, 2014) |
|                                           | Dairy cattle  | 106.7 | (IPCC, 2014) |

**Energy factors of agricultural production inputs**

| Seed (MJ/kg)                  | Wheat (Spring) | 17.9 | (Wen and Pimentel, 1984) |
|------------------------------|----------------|------|--------------------------|
|                              | Maize          | 104.65 | (Pimentel, 1980) |
|                              | Cotton         | 22.024 | (Huang et al., 2004) |
|                              | Sunflower      | 38.312 | The mean of other crops |
|                              | Alfalfa        | 108.82 | (Wen and Pimentel, 1984) |
|                              | Tomato         | 16.33  | (Lu, 1994) |
|                              | Chili          | 1.5    | (Ozkan et al., 2004) |
|                              | Melon          | 2.3    | (Ozkan et al., 2004) |
| Fertilizer (MJ/kg)           | N              | 78.1   | (Pimentel, 1980) |
|                              | P              | 17.4   | (Pimentel, 1980) |
| Category                          | Item                  | Energy Density (MJ/kg or MJ/kwh) | Source                                  |
|----------------------------------|------------------------|----------------------------------|-----------------------------------------|
| Farmyard manure                  | Animal manure          | 14.63                            | (Wen and Pimentel, 1984)                |
|                                  | Herbicides             | 278                              | (Pimentel, 1980)                       |
| Pesticide (MJ/kg)                | Insecticides           | 233                              | (Pimentel, 1980)                       |
|                                  | Fungicides             | 121                              | (Pimentel, 1980)                       |
| Mulch (MJ/kg)                    | Plastic mulch          | 51.9                             | (Cheng et al., 2011)                   |
| Fuel (MJ/kg)                     | Diesel                 | 47.78                            | (Cheng et al., 2011)                   |
| Electricity (MJ/kWh)             | Electricity for irrigation | 12                          | (Pimentel, 1980)                       |
| Machinery manufacture (MJ/kg)    | Agricultural machinery | 86.77                            | (Pimentel, 1980)                       |
| Machinery depreciation (MJ/kg/year) | Agricultural machinery | 5.21                           | (Wen and Pimentel, 1984)               |
| Coal (MJ/kg)                     | Fire coal              | 22.28                            | (Liu et al., 2017)                     |
|                                  | Male                   | 0.68                             | (Nautiyal et al., 1998)                |
|                                  | Female                 | 0.52                             | (Nautiyal et al., 1998)                |
| Human Labor (MJ/h)               | Wheat hay              | 15.05                            | (Wang et al., 2004)                    |
|                                  | Maize                  | 15.22                            | (Wang et al., 2004)                    |
|                                  | Alfalfa hay            | 18.8                             | (Wang et al., 2004)                    |
|                                  | Maize                  | 18.26                            | (Wang et al., 2004)                    |
|                                  | Soybean                | 18.83                            | (Wang et al., 2004)                    |
|                                  | Wheat husk             | 13.72                            | (Wang et al., 2004)                    |
| Energy factors of agricultural products | Wheat (Spring)          | 12.56                            | (Wang et al., 2004)                    |
|                                  | Maize                  | 18.26                            | (Wang et al., 2004)                    |
|                                  | Cotton                 | 22.024                           | (Huang et al., 2004)                   |
|                                  | Sunflower              | 10.4                             | The mean of other crops                |
|                                  | Tomato                 | 1.258                            | (Huang et al., 2004)                   |
|                                  | Chili                  | 1.258                            | (Huang et al., 2004)                   |
|                                  | Melon                  | 1.6722                           | (Huang et al., 2004)                   |
| Hay (MJ/kg)                      | Wheat (Spring)         | 15.05                            | (Wang et al., 2004)                    |
|                                  | Maize                  | 15.22                            | (Wang et al., 2004)                    |
|                                  | Alfalfa                | 18.8                             | (Wang et al., 2004)                    |
| Livestock products (MJ/kg) | Cotton | 18.3 | (Wang et al., 2017) |
|----------------------------|--------|------|---------------------|
| Lamb                       |        | 12.877 | (Huang et al., 2004) |
| Beef                       |        | 13.88 | (Huang et al., 2004) |
| Milk                       |        | 2.889 | (Huang et al., 2004) |
| Wool                       |        | 23.41 | (Wen and Pimentel, 1984) |
Table 4 (on next page)

Parameters of crop production and pasture (rangeland) for the calculation of carbon stock.
Table 4 Parameters of crop production and pasture (rangeland) for the calculation of carbon stock.

| Crops          | Harvest Index (%) | Water content (%) | Carbon absorption ratio (%) | Root-shoot ratio (%) | References                  |
|----------------|-------------------|-------------------|----------------------------|----------------------|-----------------------------|
| Wheat (Spring) | 40                | 13                | 48.53                      | 14                   | (Tian and Zhang, 2013)     |
| Corn           | 40                | 14                | 47.09                      | 16                   | (Tian and Zhang, 2013)     |
| Cotton         | 38.3              | 9                 | 45                         | 19                   | (Tian and Zhang, 2013)     |
| Sunflower      | 31                | 10                | 45                         | 30.6                 | (Miao et al., 1998)        |
| Tomato         | 60                | 90                | 45                         | -                    | (Tian and Zhang, 2013)     |
| Chili          | 60                | 90                | 45                         | -                    | (Tian and Zhang, 2013)     |
| Melon          | 70                | 90                | 45                         | -                    | (Tian and Zhang, 2013)     |
| Alfalfa        | 35                | 83                | 45                         | 0.178                | (Qi et al., 2011)          |
| Grass (rangeland) | 35            | 83                | 45                         | 7.7                  | (Jian, 2001)               |
Table 5 (on next page)

Energy balances, net energy ratio and net income from agricultural production systems in Minqin Oasis.
Table 5 Energy balances, net energy ratio and net income from agricultural production systems in Minqin Oasis.

|                     | ICP | ICLP | IFLP | EGLP | SED\(^1\) | P-Value |
|---------------------|-----|------|------|------|-----------|---------|
| **Energy balances (GJ/Farm)** |     |      |      |      |           |         |
| **Crop**            |     |      |      |      |           |         |
| Input               | 72.0| 63.8 | -    | -    | -         |         |
| Output              | 74.0| 70.4 | -    | -    | -         |         |
| Balance             | 2.1 | 6.7  | -    | -    | -         |         |
| NER\(^2\)           | 1.03| 1.09 | -    | -    |           |         |
| **Livestock**       |     |      |      |      |           |         |
| Input               |     | 1.7\(^c\) | 201.0\(^a\) | 27.6\(^b\) | 5.31     | <0.001  |
| Output              |     | 4.3\(^c\) | 153.0\(^a\) | 75.3\(^b\) | 7.77     | <0.001  |
| Balance             |     | 3.0\(^b\) | -48.5\(^c\) | 47.8\(^a\) | 2.26     | <0.001  |
| NER\(^2\)           |     | 2.58\(^b\) | 0.63\(^b\) | 2.74\(^a\) | 0.063    | <0.001  |
| **Crop + Livestock**|     |      |      |      |           |         |
| Input               | 72.0\(^b\) | 65.0\(^b\) | 201.0\(^a\) | 27.6\(^c\) | 6.24     | <0.001  |
| Output              | 74.0\(^b\) | 75.9\(^b\) | 153.0\(^a\) | 75.3\(^b\) | 8.92     | <0.001  |
| Balance             | 2.1\(^c\) | 11.7\(^b\) | -48.5\(^d\) | 51.8\(^a\) | 2.31     | <0.001  |
| NER\(^2\)           | 1.03\(^c\) | 1.17\(^b\) | 0.63\(^d\) | 2.74\(^a\) | 0.081    | <0.05   |
| **Crop & Rangeland (GJ/ha farmland)** |     |      |      |      |           |         |
| Input               | 86.58\(^a\) | 76.42\(^b\) | -    | 0.001\(^c\) | 1.608    | <0.001  |
| Output              | 89.79 | 98.97\(^a\) | -    | 0.002\(^c\) | 1.855    | <0.001  |
| Balance             | 3.22\(^b\) | 22.55\(^a\) | -    | 0.001\(^c\) | 0.581    | <0.001  |
| NER\(^2\)           | 1.04\(^c\) | 1.20\(^b\) | -    | 2.09\(^a\) | 0.02     | <0.001  |
| **Net income (1,000¥/Farm)** |     |      |      |      |           |         |
| Net income          | 24.7\(^d\) | 32.0\(^c\) | 46.4\(^a\) | 39.1\(^b\) | 9.78     | <0.001  |

\(^1\)SED: standard error of differences; \(^2\)NER: net energy ratio=output energy/input energy; dissimilar letters (a, b, c) indicates a significant difference (\(P<0.05\)); similar letters: no significant difference.
**Table 6 (on next page)**

GHG emissions, carbon stock, carbon balance, and carbon economic efficiency of agricultural production systems in Minqin Oasis.
Table 6 GHG emissions, carbon stock, carbon balance, and carbon economic efficiency of agricultural production systems in Minqin Oasis.

|                                      | ICP | ICLP | IFLP | EGLP | SED\(^1\) | P-Value |
|--------------------------------------|-----|------|------|------|-----------|---------|
| **Carbon balance (tonne CO\(_2\)-eq /farm)** |     |      |      |      |           |         |
| **Crop & Rangeland**                 |     |      |      |      |           |         |
| GHG emissions\(^2\)                  | 10.2\(^b\) | 9.2\(^b\) | -    | 9,980.0\(^a\) | 181.22   | <0.05   |
| Carbon stock\(^3\)                   | 7.6\(^b\) | 8.5\(^b\) | -    | 39,400.0\(^a\) | 716.60   | <0.05   |
| Carbon balance\(^4\)                 | -2.5\(^b\) | -0.7\(^b\) | -    | 29,541.0\(^a\) | 535.51   | <0.05   |
| **Livestock**                        |     |      |      |      |           |         |
| GHG emissions\(^5\)                  | -   | 5.9\(^c\) | 154.6\(^a\) | 63.7\(^b\) | 3.61     | <0.001  |
| Carbon stock\(^6\)                   | -   | 0.2\(^c\) | 6.5\(^a\) | 2.7\(^b\) | 148.63   | <0.001  |
| Carbon balance\(^7\)                 | -   | -5.6\(^a\) | -148.1\(^c\) | -61.1\(^b\) | 3.44     | <0.001  |
| **Crop & Rangeland + Livestock**     |     |      |      |      |           |         |
| GHG emissions                        | 10.2\(^c\) | 15.0\(^c\) | 154.5\(^b\) | 10,042.0\(^a\) | 141.23   | <0.05   |
| Carbon stock                         | 7.6\(^b\) | 8.7\(^b\) | 6.5\(^b\) | 39,430.0\(^a\) | 557.61   | <0.05   |
| Carbon balance                        | -2.5\(^b\) | -6.3\(^b\) | -148.1\(^c\) | 29,390.0\(^a\) | 416.4    | <0.001  |
| **Carbon economic efficiency (¥/kg CO\(_2\)-eq /farm)** |     |      |      |      |           |         |
| **Crop & Rangeland**                 | 5.12\(^a\) | 5.24\(^a\) | -    | 3.26\(^b\) | 0.041    | <0.05   |
| **Livestock**                        | -   | 2969.0\(^a\) | 2771.0\(^b\) | 3,015.0\(^a\) | 25.94    | <0.05   |
| **Crop & Rangeland + Livestock**     | 5.12\(^b\) | 10.19\(^b\) | 2771.0\(^a\) | 55.09\(^b\) | 53.813   | <0.05   |
| **Crop & Rangeland (tonne CO\(_2\)-eq /ha farmland)** |     |      |      |      |           |         |
| GHG emissions                        | 12.7\(^a\) | 12.6\(^a\) | -    | 5.6\(^b\) | 0.13     | <0.05   |
| Carbon stock                         | 9.6\(^c\) | 12.1\(^b\) | -    | 22.2\(^a\) | 0.22     | <0.001  |
| Carbon balance                        | -3.2\(^c\) | -0.6\(^b\) | -    | 16.6\(^a\) | 0.34     | <0.001  |

\(^1\)SED: standard error of differences; \(^2\)GHG emissions from crop production inputs; \(^3\)carbon stock of the net accumulation of photosynthesis from crop products, such as the grain, stem, and root; \(^4\)carbon balances of crop production, carbon balance=carbon stock - GHG emissions; \(^5\)GHG emissions from livestock production; \(^6\)carbon stock from livestock products, such as the carcass, milk and wool; \(^7\)carbon balances of livestock production, carbon balance=carbon stock - GHG emissions; dissimilar letters (a, b, c) indicates a significant difference (P<0.05); similar letters: no significant difference.
Table 7 (on next page)

Energy balances, GHG emissions, carbon economic efficiency and net energy ratio of crop grown in the Minqin Oasis.
Table 7: Energy balances, GHG emissions, carbon economic efficiency and net energy ratio of crop grown in the Minqin Oasis.

|                              | Wheat (spring) | Maize | Cotton | Sunflower | Chili | Tomato | Melon | Alfalfa | SED | P-Value |
|------------------------------|----------------|-------|--------|-----------|-------|--------|-------|---------|------|---------|
| Energy balances (GJ/ha)      |                |       |        |           |       |        |       |         |      |         |
| Input                        | 90.5           | 76.5  | 51.0   | 50.1      | 101.2 | 105.0* | 105.5*| 44.5    | 11.21| <0.001  |
| Output                       | 188.5          | 201.0 | 70.0   | 66.0      | 65.5  | 66.5   | 67.0  | 178.5   | 91.22| <0.001  |
| Balance                      | 98.1           | 124.3 | 19.1   | 14.1      | -34.3 | -38.5  | -38.3 | 134.2   | 81.01| <0.001  |
| NER²                         | 2.08           | 2.63  | 1.40   | 1.31      | 0.65* | 0.63* | 0.64* | 4.01    | 0.447| <0.001  |
| Carbon balance (Ton CO₂-eq/ha)|                |       |        |           |       |        |       |         |      |         |
| Emissions³                   | 10.55          | 12.71*| 10.15  | 12.46     | 12.24 | 12.82  | 12.69*| 8.73    | 0.031| <0.001  |
| Stock⁴                       | 12.25          | 24.57 | 5.88   | 7.16      | 1.45  | 5.51   | 0.11  | 11.64   | 0.145| <0.001  |
| Balance⁵                     | 1.70           | 11.86 | -4.27  | -5.31     | -10.8 | -7.31  | -12.6 | 2.91    | 0.149| <0.001  |
| Carbon economic efficiency (¥/kg CO₂-eq.)| 1.79* | 1.89  | 2.12   | 1.55      | 2.03**| 3.24   | 1.77* | 2.08** | 0.099| <0.001  |

¹SED: standard error of differences. ²NER: net energy ratio = output energy/input energy.
³GHG emissions from crop production input. ⁴carbon stock of the net deposition of photosynthesis from crop products, such as grain, stem, and root; carbon balances of crop production; ⁵carbon balances of crop production, Balance = stock-emissions; (*) and (**) : significant difference only exists between values with different asterisk number – i.e. there is significant difference between single (*) and double (**) asterisk values; no significant difference exists between values with the same asterisk number –i.e. there is no significant difference between (**) and (**) values.
Table 8 (on next page)

The standardized direct, indirect, and total effects between dependent variables and predicted variables.
Table 8 The standardized direct, indirect, and total effects between dependent variables and predicted variables.

| Fig. 4 | No. of | Dependent Variables | Predicted variables | Direct effects | Indirect effects | Total Effects |
|--------|--------|----------------------|---------------------|---------------|-----------------|--------------|
| Fig. 4 (a) | 1 | OtoD<sup>1</sup> | ECO<sup>6</sup> | 0.000 | 0.120 | 0.120 |
| | | SPD<sup>2</sup> | ECO | -0.179 | 0.833 | 0.654 |
| | | PS<sup>3</sup> | ECO | -0.566 | -0.668 | -1.234 |
| | | WUE<sup>4</sup> | ECO | 0.381 | -0.994 | -0.613 |
| | | BS<sup>5</sup> | ECO | 0.769 | 0.000 | 0.769 |
| Fig. 4 (b) | 2 | OtoD | EB<sup>7</sup> | 0.000 | -0.904 | -0.904 |
| | | SPD | EB | 0.107 | 0.456 | 0.564 |
| | | PS | EB | -0.333 | 0.677 | 0.343 |
| | | WUE | EB | 0.828 | 0.164 | 0.992 |
| | | BS | EB | -0.127 | 0.000 | -0.127 |
| Fig. 4 (c) | 3 | OtoD | CB<sup>8</sup> | 0.000 | -0.705 | -0.705 |
| | | SPD | CB | 0.098 | 1.106 | 0.924 |
| | | PS | CB | -0.93 | 0.732 | -0.198 |
| | | WUE | CB | 0.406 | 0.518 | 1.204 |
| | | BS | CB | -0.401 | 0.000 | -0.401 |
| Fig. 4 (d) | 4 | OtoM<sup>9</sup> | ECO | 0.000 | 0.102 | 0.102 |
| | | SPD | ECO | -0.182 | 0.885 | 0.703 |
| | | PS | ECO | -0.575 | -0.498 | -1.073 |
| | | WUE | ECO | 0.387 | -1.419 | -1.031 |
| | | BS | ECO | 0.762 | 0.000 | 0.762 |
| Fig. 4 (e) | 5 | OtoM | EB | 0.000 | 0.941 | 0.941 |
| | | SPD | EB | 0.108 | -0.32 | -0.212 |
| | | PS | EB | -0.335 | 0.659 | 0.323 |
| | | WUE | EB | 0.832 | 0.232 | 1.064 |
| | | BS | EB | -0.124 | 0.000 | -0.124 |
| Fig. 4 (f) | 6 | OtoM | CB | 0.000 | 0.933 | 0.933 |
| | | SPD | CB | 0.099 | 0.54 | 0.639 |
| | | PS | CB | -0.939 | 0.651 | -0.288 |
| | | WUE | CB | 0.41 | 0.734 | 1.144 |
| | | BS | CB | -0.395 | 0.000 | -0.395 |

<sup>1</sup>OtoD: the distance from the oasis to the desert (km); <sup>2</sup>SPD: soil particle diameter (μm); <sup>3</sup>PS: planting structure (planting crop type); <sup>4</sup>WUE: water use efficiency (MJ/m³); <sup>5</sup>BS: breeding structure (breeding livestock category); <sup>6</sup>ECO: net income (1,000¥/farm); <sup>7</sup>EB: Energy balances (GJ/farm); <sup>8</sup>CB: carbon stock minus GHG emissions from agricultural production input (tonne...
$^{9}\text{OtoM}$: the distance from the oasis to the desert (km). Shading indicates the greatest positive direct effect, indirect effect, and total effect between dependent and independent variables.