nature research

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Last updated by author(s): Jul 7, 2021

Reporting Summary

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Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used for data collection. All data were collected from four long-term field experiments based on maize (Zea mays L.) intercropped with one or more of the following five crops - wheat (Triticum aestivum L.), faba bean (Vicia faba L.), soybean [Glycine max (L.) Merrill], chickpea (Cicer arietinum L.), and oilseed rape (Brassica napus L.) in Gansu and Ningxia Provinces in northwest China.
Data analysis	The data analysis was conducted in R version 3.6.2.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

The data that support the findings of this study are available at https://figshare.com/account/home#/data and from the corresponding author upon request.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description

To explore the long-term costs and benefits of intercropping relative to monocultures, we conducted four field experiments at sites in Gansu and Ningxia Provinces in northwest China that spanned a substantial soil fertility and yield production gradient (Supplementary Table 1). For the two "Equal Fertilizer" experiments (Baiyun-1 and a portion of Hongsibu), all monoculture and intercropped plots received identical fertilization treatments. For the three "Optimal Fertilizer" experiments (Baiyun-2, Jingtan and Hongsibu), monocultures of each crop received agronomically optimal fertilization, and intercrops received the higher rate, that recommended for maize. The experiment at the Baiyun-1 site was a single factor completely randomized block design with three monocultures (maize, wheat and faba bean), three continuous intercropping systems (two crops continuously intercropped on the same strips of land for each crop every year, crop combinations included maize/faba bean, faba bean/wheat, and maize/wheat), three rotational intercropping systems (two crops rotationally intercropped with one crop strips in one year and the other crop strips in subsequent year, crop combination included maize/faba bean, faba bean/wheat, and maize/wheat), and four rotation systems (wheat-faba bean, wheat-maize, maize-faba bean, and wheat-maize-faba bean). There were three replications for each treatment and a total 39 plots. The experiments at the Baiyun-2 and Jingtan sites were a split-plot completely randomized block design with nine replications of monocultures of maize, faba bean, soybean, chickpea and oilseed rape, and nine replications of maize intercropped with faba bean, soybean, chickpea and oilseed rape. These were divided into three replications of each treatment at each of three P application levels (0, 40, and 80 kg P ha-1 yr-1), where there were 81 plots for each experiment. The Equal Fertilization experiment at the Hongsibu has treatments of faba bean/maize intercropping, and faba bean and maize monoculture. Plots received the identical N application rates, with one rate at 75 kg N ha-1 yr-1, and the other at 150 kg N ha-1 yr-1. Each of three block sets had plots with inoculation by rhizobia (R. leguminosarum bv. viciae NM353), and without inoculation. The Optimal Fertilization experiment at Hongsibu was a split-split-plot completely randomized block design, identical to the Hongsibu Equal Fertilization experiment, except faba bean, because it is a legume, received half the N fertilizer of maize. Specifically, each rhizobia treatment was divided into three replications at each of five N levels (0, 75, 150, 225, and 300 kg N ha-1 yr-1 for monoculture of maize and intercropping; 0, 37.5, 75, 112.5, and 150 kg N ha-1 yr-1 for monoculture of faba bean). More experimental details for the four sites are in Supplementary Table 2.

Research sample

Our four long-term experiments were based on maize (Zea mays L.) intercropped with one or more of the following five crops - wheat (Triticum aestivum L.), faba bean (Vicia faba L.), soybean [Glycine max (L.) Merrill], chickpea (Cicer arietinum L.), and oilseed rape (Brassica napus L.). In all of these intercropping and monoculture systems, we measured crop and soil properties, including total grain yields (n = 4332,) soil nutrient chemistry (n = 2169), soil aggregate size (n = 4572), the year-to-year temporal stability (n = 423) of the intercrops and their monocultures, and net farmer profits (n = 126).

Sampling strategy

For all experiments, a central strip of the individual crop species (5.6 m in length × 1.6 m in width at Baiyun-1, 5.5 m in length × 1.4 m in width at Baiyun-2, 6.0 m in length × 1.4 m in width at Jingtan, and 3.0 m in length × 1.2 m in width at Hongsibu) was hand-harvested in each plot for grain yield after full maturity every year from the starting of experiments through 2018. Grain yields of the two component crops were harvested separately and then summed to determine the total grain yield in intercropping. Soil samples were collected from the top 20 cm of the profile using an auger (35 mm diameter) from 2011 to 2012 at Baiyun-1 and Baiyun-2, and from 2012 to 2014 at Jingtan and Hongsibu. Four soil cores were collected from each plot and combined to give one composite sample per plot for monocultures and there also were four sampling points for each crop strip per plot in intercropping. The composite samples were air-dried and sieved through a 2 mm mesh and finally placed in plastic bags for chemical analysis. The undisturbed soil samples were collected using an aluminum box (8.0 cm diameter) from surface soil depth (0-20 cm) of each plot after maize harvest from 2011 to 2014 at Baiyun-1 and Baiyun-2, from 2012 to 2014 at Jingtan and Hongsibu, air-dried under shade for several days, and then gently transported to the laboratory for subsequent soil aggregate determination. In soil aggregate sampling, one sample was collected from monoculture plots and two samples from intercropped plots. Sampling for soil aggregate and chemical properties generally was after all crops were harvested in early October.

Data collection

In order to compare the total productivity of monoculture and intercropping systems at a comparable fertilization level, we used the weighted means of grain yield in monoculture systems. We also considered that Land Equivalent Ratio (LER) and partial Land Equivalent Ratio (PLER) are relative metrics of intercropping advantage. Temporal stability was defined for each plot as μ/σ, where μ is the temporal mean of grain yield and σ its temporal standard deviation during the study period. We next removed yield variation attributable to a temporal trend of increasing crop yield by regressing annual crop yields on the year for each experimental site. For each regression, the σ of the residuals provided the measure of detrended variation of yield that was used to calculate the temporal stability of grain yield. Net profit is the difference between total income and expenditure. Total income comes mainly from grain yield of crops. Total expenditure includes NP fertilizer, seeds, and irrigation costs as well as the salary of workers who manage the fields, including weeding, sowing and harvesting during study period. The selling prices of grain for chickpea, faba bean, maize, oilseed rape, soybean, and wheat were 5.6, 4.8, 1.9, 4.9, 4.0, and 2.2 CNY per kg, respectively. The inputs of N and P fertilizers were respective 4.1 and 4.6 CNY per kilogram. The conventional dose of N fertilizer used in the study region was 225 kg ha-1 yr-1 for monocultures of wheat and maize crops and all maize-based intercropping systems, and of P fertilizer was 40 kg ha-1 yr-1 for all cropping systems. The inputs of seeds, labor cost, and irrigation were determined according to the current market prices. Exchange rate was 1US$ ≈ 6.53 CNY. All authors of the paper, except for two authors from USA, were involved in the yield data collection from field experiment

	in past 16 years (at Baiyun-1) and 10 years (at Baiyun-2, Jingtan, and Hongsibu). Xiao-Fei Li and Zhi-Gang Wang collected data for soil properties in these studies.
Timing and spatial scale	The time scale of our four field experiments was more than 10 years (one for 16 years from 2003 through 2018 and three for 10 years from 2009 through 2018). These experiments spanned a substantial soil fertility gradient and covered major food and oil crops in northwest China. Sampling for soil aggregate and chemical properties generally was after all crops were harvested in early October.
Data exclusions	No data were excluded from the analyses.
Reproducibility	In the long-term field experiments, the yields were measured every year after crops were full mature. The soil properties were repeatedly measured for two or four years. All attempts to repeat the analysis and results were successful.
Randomization	The field arrangement for experimental plots were completely randomized block design. Soil samples were collected randomly within monocultured plots or within crop strip in intercropping plots.
Blinding	The collected soil cores and analysis were numbered and only later linked to the different treatments.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	The experiment at the Baiyun-1 site was initiated in 2003, and the remaining of experiments at the Baiyun-2, Jingtan, and Hongsibu sites were initiated in 2009. Total average precipitation for these sites is 150, 200 and 185 mm, respectively. The mean annual temperatures are 7.7, 6.6, and 8.9°C.
Location	Experiments were conducted across Gansu and Ningxia Provinces for a total of four sites at Baiyun-1 (38°37′N, 102°40′E), Baiyun-2 (38°37′N, 102°40′E), Jingtan (37°05′N, 104°40′E), and Hongsibu (37°25′N, 106°03′E) where are the Experimental Stations of Gansu Academy of Agricultural Sciences and Ningxia Academy of Agriculture and Forestry Sciences, China.
Access & import/export	The research was carried out under the National Science Foundation of China (31430014), the National Key Research and Development Program of China (2016YFD0300202) and the National Science Foundation EPSCoR Cooperative Agreement OIA-1757351.
Disturbance	There was no disturbance.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging