**META-ANALYSIS** 



# Improvement of nutritional quality of food crops with fertilizer: a global meta-analysis

Muhammad Ishfaq<sup>1</sup> · Yongqi Wang<sup>1</sup> · Jiuliang Xu<sup>1</sup> · Mahmood Ul Hassan<sup>1</sup> · Hao Yuan<sup>1</sup> · Lianlian Liu<sup>1</sup> · Boyi He<sup>1</sup> · Irsa Ejaz<sup>2</sup> · Philip J. White<sup>3</sup> · Ismail Cakmak<sup>4</sup> · Wei-Shan Chen<sup>5</sup> · Jiechen Wu<sup>6</sup> · Wopke van der Werf<sup>7</sup> · Chunjian Li<sup>1</sup> · Fusuo Zhang<sup>1</sup> · Xuexian Li<sup>1</sup>

Accepted: 6 September 2023 © The Author(s) 2023

#### Abstract

Providing the world's population with sufficient and nutritious food through sustainable food systems is a major challenge of the twenty-first century. Fertilizer use is a major driver of crop yield, but a comprehensive synthesis of the effect of fertilizer on the nutritional quality of food crops is lacking. Here we performed a comprehensive global meta-analysis using 7859 data pairs from 551 field experiment-based articles published between 1972 and 2022, assessing the contribution of fertilization with a wide set of plant nutrients to the nutritional quality of food crops (i.e., fruits, vegetables, cereals, pulses/oil crops, and sugar crops). On average, fertilizer application improved crop yield by 30.9% (CI: 28.2–33.7%) and nutritional quality (referring to all nutritionally relevant components assessed; carbohydrates, proteins, oil, vitamin C, representative mineral nutrients, and total soluble solids) by 11.9% (CI: 10.7–12.1%). The improvements were largely nutrient- and crop species in promoting crop nutritional quality, whereas the combined application of inorganic and organic source(s) had the greatest impact on quality. Desirable climatic conditions and soil properties (i.e., silt loam, soil organic matter 2.5–5.0%, and pH 4.5–8.5) supported further enhancements. Considering cross-continent responsiveness, the increase in the nutritional quality of food crops with fertilizer application was greatest in Africa. In a nutshell, our findings pave the way towards a quantitative understanding of nutrient management programs and responsible plant nutrition solutions that foster the sustainable production of nutritions and healthy food crops for human consumption.

**Keywords** Soil and environmental conditions  $\cdot$  Soil fertility and plant nutrition  $\cdot$  Agriculture production  $\cdot$  Biofortification  $\cdot$  Human health  $\cdot$  Food security

Xuexian Li steve@cau.edu.cn

- <sup>1</sup> Department of Plant Nutrition, College of Resources and Environmental Sciences; the State Key Laboratory of Nutrient Use and Management (SKL-NUM), Ministry of Education, China Agricultural University, Beijing 100193, China
- <sup>2</sup> College of Agronomy and Biotechnology, China Agricultural University, Beijing 100193, China
- <sup>3</sup> Ecological Sciences Department, The James Hutton Institute, Invergowrie, Dundee DD2 5DA, UK

- <sup>4</sup> Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul 34956, Turkey
- <sup>5</sup> Environmental Technology Group, Wageningen University & Research, 6700, AK, Wageningen, The Netherlands
- <sup>6</sup> Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden
- <sup>7</sup> Centre for Crop Systems Analysis, Wageningen University, 6700, AK, Wageningen, The Netherlands



#### 1 Introduction

Food security has been defined by the Food and Agriculture Organization of the United Nations as "a situation that exists when all people have physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences for an active and healthy life" (FAO 1996; FAO 2021a). It encompasses food supply, food safety, and the nutritional quality of products that deliver required amounts of proteins, energy, vitamins, and essential mineral nutrients (Global Panel 2016; Menichetti et al. 2022). The prevalence of micronutrient deficiencies, also known as the "hidden hunger," has serious health and economic consequences, especially in low- and middle-income countries (Smith and Haddad 2015; Gödecke et al. 2018; UNICEF 2019; Murray et al. 2020). Undernutrition (lack of carbohydrates and micronutrient malnutrition) remains a persistent problem despite more coordinated global efforts to overcome it in the past decades (Byerlee and Fanzo 2019; Heidkamp et al. 2021). Recent estimates suggest that globally  $\sim$  720–811 million people are facing chronic hunger and 2.37 billion people are affected by moderate to severe nutrition insecurity, with the majority of these in Asia and Africa (Wessells and Brown 2012; FAO 2021a). On the other hand, adult obesity rates also continue to rise, with the global prevalence up to 13.1% in 2016 (FAO/IFAD/UNICEF/WFP/WHO 2020). These statistics highlight a major challenge to achieving the United Nations' zero hunger (SDG2) and good health and well-being (SDG3) Sustainable Development Goals (SDGs) by 2030 (FAO 2019; FAO/IFAD/UNICEF/WFP/ WHO 2020; Heidkamp et al. 2021). Particular attention is, therefore, required to establish sustainable and equitable food security systems.

To address SDG2 and SDG3, the worldwide agriculture sector must meet the twin challenges of producing sufficient food and meeting the nutritional demands of the growing population in a sustainable manner (Ruel et al. 2018; Dobermann et al. 2022). Plant breeding, crop and soil management, and fertilizer application are acknowledged approaches for enhancing the yield and nutritional quality of agricultural products (White and Broadley 2005a; Cakmak 2008; White and Broadley 2009; Cakmak and Kutman 2018; Ishfaq et al. 2021a). Impressive progress has been made in understanding mechanisms of nutrient acquisition and their transport and functions in plants (Grotz and Guerinot 2006; Marschner 2012; Oldroyd and Leyser 2020; Assunção et al. 2022). Nevertheless, fertilizer programs implemented in the past have mainly focused on improving crop yields, and little priority has been given to nutritional outcomes for human health (Welch et al. 2013). Indeed, the nutritional value of food crops has sometimes declined due to narrower crop genetics, intensive cultivation practices, and depletion of soil nutrients (Shewry et al. 2016; Marles et al. 2017; Moreno-Jiménez et al. 2021; Ishfaq et al. 2022a). For instance, a decline in dietary potassium (K) intake and a rise in hypokalemia prevalence is reported in the US population (Sun and Weaver 2020), and low dietary intake of essential mineral elements in Western countries is widely documented (White and Broadley 2005b; Eussen et al. 2015; Ruxton et al. 2016; Vural et al. 2020). Similarly, an inverse relationship was found between the phytoavailability of mineral nutrients in the cultivated soil and related nutritional disorders in the population of sub-Saharan Africa (Cakmak et al. 2016; Kihara et al. 2020; Gashu et al. 2021). The imbalanced or excessive intake of certain minerals leads to serious health concerns; for example, a higher ratio of sodiumto-K increases the risks of cardiovascular diseases (Cook et al., 2009; Wakeel and Ishfaq 2022). Thus, a new paradigm for agriculture that considers both yield and nutritional composition is required (Poole et al. 2020; Brown et al. 2021; Dobermann 2022).

Plants require at least fourteen mineral elements in addition to carbon, hydrogen, and oxygen and more than 20 mineral elements have been identified as being essential for human health (White and Brown 2010; Marschner 2012; Brown et al. 2021). Many of these elements enter the food system through the soil, supplemented by applied fertilizers, organic amendments, and a few other sources (i.e., biological nitrogen fixation, deposition, and weathering of rocks and minerals). Depending on the local context, the biofortification of staple crops, either through genetic biofortification or agronomic biofortification, can be an effective strategy for combating malnutrition (Cakmak 2008; White and Broadley 2009; Bouis and Saltzman 2017; Ishfaq et al. 2021a). Furthermore, nutrient availability is strongly driven by soil physicochemical properties and climatic conditions, and greater insight is required to understand which growth conditions can be employed to obtain superior crop productivity and better nutritional quality. There is a need for synthesis of the available information in the literature to quantify how much different fertilization strategies contribute to the concentration of nutritionally relevant components of food crops. Such a synthesis would clarify the effectiveness of different strategies for different constituents of food and would also clarify the effects of other variables, such as soil properties and climate.

Here we performed the first comprehensive global metaanalysis to provide fundamental insights into the contribution of a wide set of plant nutrients to the nutritional value of food



<b>Fa</b> t	ble	1	]	Descript	ion of	specif	fic t	erms	used	in 1	this	stud	y.
-------------	-----	---	---	----------	--------	--------	-------	------	------	------	------	------	----

Terminology	Description					
Nutritional quality	Nutritionally relevant components such as carbohydrates, proteins, oils, vitamin C, lycopene/carotenoids, mineral nutrients, and total soluble solids (TSS) in the edible portions of food crops. Their concentration per unit weight is retrieved from reported studies, and given numbers across all crops or within individual crop types indicate grand mean values which were generated by the random effect meta-analysis model.					
Mineral nutrients	A collection of nutritionally important nutrients for human health including potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe)					
Food crops	Classified as fruits, vegetables, cereals, pulses/oil crops, and sugar crops					
Agricultural/crop produce	Edible portions of different food crops					
Responsible plant nutrition	Fertilizer applications considering food production and consumption in a sustainable manner					
Balanced nutrient provision	Adequate supply of essential nutrients to plants in order to minimize over or under-supply					
Organic sources/amendments	Classified as organic fertilizers, farm yard manure (FYM), green manure, crop residues, poultry manure, vermicompost, sawdust, biofertilizers					
Combined fertilizer application	Application of different types of fertilizers					
Substitution ratios	Replacement of specific amounts of inorganic fertilizers with organic sources/amendments					

crops. A detailed description of specific terms used in this study (Table 1) and a schematic illustration are provided (Fig. 1). By using 7859 data pairs from 551 field experiments-based articles of more than 90 different crop plants on six continents which were published in the last 50 years, we (i) report how fertilizer practices influence the nutritional composition of produce in a nutrient- and crop species-dependent manner; (ii) provide information on the effects of site-specific covariates such as climatic conditions and soil properties on improving the nutritional quality of plant products; and (iii) assess the relationships between yield and nutritional value of different food crops. The findings of this study provide a useful quantitative framework to assess the changes in the nutritional quality of food crops affected by fertilizer application and offer effective plant nutrition solutions to increase the production of nutritious food and contribute to the well-being of human populations.

# 2 Materials and methods

#### 2.1 Data mining and validation

An extensive literature survey was conducted through the Web of Science database (http://apps.webofknowl edge.com/), Google Scholar (http://scholar.google.com), and the China National Knowledge Infrastructure Database (http://www.cnki.net/) until March 2022. To retrieve articles from the databases, the following search terms were used: ("food\* crop" OR "fruit" OR "vegetable" OR "cereal" OR "wheat" OR "maize" OR "rice" OR "grain" OR "legume" OR "pulses" OR "oil crop" OR "sugar crop") AND ("fertilizer\*" OR "macronutrient" OR "N" OR "P" OR "K" OR "Ca" OR "Mg" OR "S" OR "OR "NPK" OR "micronutrient" OR "Zn" OR "Fe" OR "organic source" OR "FYM" OR "compost") AND ("food\* quality" OR "carbohydrate" OR "protein" OR "oil" OR "vitamin





C" OR "lycopene" OR "carotenoid" OR "nutrient" OR "total soluble solid"). The Boolean truncation ("\*") was employed to ensure that all variants of keywords would be found. To refine the metadata search, two logical operators (AND and OR) and field tag (TI = title) were used. In addition, references to related articles were reviewed to retrieve relevant information. Peer-reviewed journal articles published from 1972 to 2022 were shortlisted following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009 and Fig. S1). We screened the retrieved articles and retained those that met the following four inclusion criteria: (i) the study was conducted under field conditions (i.e., not glasshouse, controlled environment or in vitro studies); (ii) the study included treatments of interest, including sole or combined application of fertilizer(s), and information both from a control treatment (no or very low rates of fertilizers) and a fertilized treatment at the agronomically recommended rate; (iii) yield and/or nutritional quality parameters were reported for both the treatment and control; (iv) we focused on quality parameters related to the concentration of nutritionally relevant constituents on a mass basis and did not include additional quality traits such as appearance, textural properties, aroma, size, color, cracking, and disease incidence, and treatments needed to have replicates within an experimental design allowing the calculation of the weight of individual observations.

The required data were extracted from text and tables, and to retrieve data presented graphically, the digital software Plot Digitizer (https://automeris.io/WebPlotDigitizer/) and GetData (http://www.getdata-graph-digitizer.com/) were used. The geographical coordinates of each site were recorded directly from the studies or derived by the location of the nearest city or the experimental station at which the study took place (Supplementary dataset). In our data collection, the concentration of mineral nutrients (K, Ca, Mg, Zn, and Fe) was on a dry mass basis and the concentrations of other five quality traits (carbohydrates, proteins, oils, vitamin C, and total soluble solids) were on a fresh mass basis. Besides variables related to the nutritional guality of food crops, we also collected information about sitespecific covariates such as continent, plant type, climate, and original soil properties such as soil organic carbon/matter (SOM), pH, total nitrogen (N), Olsen-phosphorus (P), exchangeable potassium (Ex-K), soil texture, and soil order according to the available data. The data about soil physical properties were collected from studies or extracted from the HWSD database (Wieder et al. 2014) using geographical coordinates. When only soil organic carbon was reported, we multiplied organic carbon by a factor two to estimate the concentration of soil organic matter (Pribyl 2010). All data used for analysis is available as Supporting Information (Supplementary dataset). Normal Quantile plot (Rosenberg



et al. 2000) and Jackknife technique (Mendenhall et al., 1995) were used to assess the publication bias and sensitivity of weighted mean effect sizes of improvement of nutritional quality and yield of food crops with fertilizer application, respectively. For a few fertilizer sources, the standardized effect sizes did not fully distribute evenly with the y = x line (Fig. S2 and S3), and 95% CIs (Fig. S4 and S5) were shifted when certain observations were removed. However, outliers would not skew the major results, and such evaluation generally supported our further analysis.

#### 2.2 Data characterization

The data for site-specific covariates such as climatic conditions were classified as temperate, tropical, subtropical, and arid and semi-arid and highlands (Li et al. 2013b, a). SOM was categorized as < 0.5%, 0.5-1%, 1-2.5%, 2.5-5%, and > 5% (Chen et al. 2007). Soil pH was grouped as < 4.5%, 4.5-5.5%, 5.5-6.5%, 6.5-7.5%, 7.5-8.5%, and > 8.5% (Han et al. 2011; Chen et al. 2018a, b). Soil total N concentration was grouped as < 60 mg kg<sup>-1</sup>, 60–125 mg kg<sup>-1</sup>, 125–250 mg kg<sup>-1</sup>, 250–500 mg kg<sup>-1</sup>, and > 500 mg kg<sup>-1</sup>, and soil Olsen-P as  $< 7 \text{ mg kg}^{-1}$ , 7–14 mg kg<sup>-1</sup>, 14–80 mg kg<sup>-1</sup>, and  $> 80 \text{ mg kg}^{-1}$  (Chen et al. 2007). Soil exchangeable K was categorized as  $< 40 \text{ mg kg}^{-1}, 40-80 \text{ mg kg}^{-1}, 80-120 \text{ mg}$  $kg^{-1}$ , 120–160 mg  $kg^{-1}$ , and > 160 mg  $kg^{-1}$  (Kirkman et al. 1994; Wakeel and Ishfaq 2022). Soil texture was classified as silt loam, sandy loam, loam and clay loam, sandy clay loam, clay, and sandy according to the USDA soil texture triangle (USDA 1999).

#### 2.3 Statistical analysis

The response ratio was calculated by dividing the response of the treatment (fertilized) by the respective response of the control. To examine the mean effects of crop nutritional quality variations with fertilizer application, we calculated the natural logarithm response ratio ( $\ln RR$ ) of each data pair (Hedges et al. 1999) as follows:

 $\ln RR = \ln(Xt/Xc) = \ln(Xt) - \ln(Xc)$ 

where the subscript Xt and Xc represents the mean value of the concerned variable in the fertilized and control, respectively. Effect size is a value reflecting the magnitude of the treatment effect in comparison to a reference treatment. The ln*RR* of the response of nutritionally important mineral nutrients (K, Ca, Mg, Zn, and Fe) to fertilizer application in a given crop group was first calculated for each mineral nutrient separately, and then a single average ln*RR* was determined across all mineral nutrients. Most of the studies included in our analysis did not report standard deviations; therefore, individual observations were weighted by the number of replications in the treatment and control (Adams et al. 1997), which was then used to calculate the mean effect sizes (ln*RR*). The equation was:

$$Wr = \left( (Nt \times Nc) / (Nt + Nc) \right)$$

where Wr is the weight associated with each  $\ln RR$ , and Nt and Nc are the number of replicates for the treatment and control, respectively. As the number of observations for yield and quality differed widely in each study, we calculated the weight factors (Wr) for yield and quality separately.

A random effect meta-analysis model was utilized for data analysis (Borenstein et al. 2011; Skinner et al. 2014). The mean and grand mean effect sizes were calculated by using METAWIN 2.1 (Rosenberg et al. 2000). The 95% bootstrapped confidence intervals (CIs) were generated by utilizing 4999 iterations. Significant responses (P < 0.05) were recognized if the 95% CI did not overlap with zero. For convenience in interpretation of results, the weighted mean effect size was converted back into a percentage change using the formula:

Percentage change(%) =  $(e^{\ln RR} - 1) \times 100$ 

To examine the relationships between site-specific covariates and yield and nutritional quality of food crops, the scatterplot matrix and linear regression model was applied, respectively.

### **3 Results**

### 3.1 Effects of fertilizers on the nutritional quality of crop products

We collected field experiment results published between 1972 and 2022 from main crop production regions across America (South America and North America), Europe, Asia, Africa, and Australia (Fig. 2a). According to data availability, a major share (4408 out of the total 7859 data pairs) was originated from China representing large variations in production situation, crop species, climatic conditions, and nutrient management.

On average across all crop species, quality traits, and fertilization treatments, fertilizer application significantly improved the concentration of diet-quality enhancing nutrients in plant produce by 11.9% (mean effect, ln*RR*; 95% confidence interval, CI: 10.7–12.1%; the number of observations, n = 5363) (Fig. 2b and Fig. S6a). Most fertilizer treatments significantly (P < 0.05) improved nutritional quality although the range varied among the type or combination(s) of applied nutrients. Crop nutritional quality was strongly increased in fertilization treatments with combined supply of N, P, K, and organic amendments (abbreviated as N + P + K

+ organic amendment(s)) (16.1%; [11.7–21.6%]), representing one of the most effective nutrient management strategies. On average, the nutritional value of produce improved by 13.7% (11.1–16.5%) with N + P + K, 13.1% (10.4–16.5%) with K, 12.8% (10.0–16.3%) with micronutrient(s), 12.1% (10.0–14.4%) with organic amendment(s), 11.1% (7.9–15.3%) with Mg, 10.6% (7.7–13.1%) with N + P, 10.5% (3.0–19.2%) with P + K, 9.4% (5.9–13.1%) with N + K, 9.1% (6.2–12.2%) with N + organic source(s), 8.1% (5.9–10.1%) with N, and 6.8% (2.9–11.1%) with S. However, application of only P (6.9%; – 1.8–15.2%) or Ca (1.3%; – 7.1–7.8%) did not significantly change the nutritional quality of crop produce.

The overall nutritional quality was then broken down into seven individual traits in association with five crop species groups (Fig. 2c and Table S1), indicating an average increase of 11.6% (10.6–12.6%; n = 5234) across all studies. Among the five crop species groups, vegetables were comparatively more responsive to fertilizer application in terms of increasing concentrations of mineral nutrients (K, Ca, Mg, Zn, and Fe) (27.9%; [22.3-34.36%]), protein (21.3%; [16.2-26.5%]), and total soluble solids (TSS) (6.3%; [4.1-8.9%]). In cereals, the concentrations of minerals elements (21.1%; [14.9-28.4%]), carbohydrates (12.5%; [8.7–18.5%]), proteins (11.4%; [9.7–13.4%]), and oil (11.1%; [5.9-23.8%]) were significantly increased by fertilizer application. In fruits, the concentrations of vitamin C increased by 14.9% (10.5-20.5%), lycopene/carotenoids by 14.8% (10.2–20.6%), carbohydrates by 12.1% (9.4–15.2%), mineral nutrients by 9.3% (2.4–17.1%), and TSS by 5.5% (4.3-6.8%) with fertilizer application. Protein concentrations in the seeds of pulses/oil crops were increased by 10.1% (7.6-13.0%) by fertilizer application, with oil concentrations unchanged (2.6%; -0.3-5.1%). By contrast, TSS was reduced by -2.7% (-4.0-1.2%) in sugar crops (comprising sugarcane and sugar beet) following fertilizer applications. Results of other nutritional quality traits in food crops were uncertain due to data limitation and were therefore not included in this study.

# 3.2 Individual and combinatorial effects of fertilizers on the nutritional quality of crop products

Quality crop production requires proper nutrient supplies based on soil conditions and developmental stages; N, P, K, and other fertilizers are applied separately or in various combinations accordingly (White and Broadley 2009; Marschner 2012; Dick et al. 2016). We analyzed how sole or combined fertilizer application affected individual quality traits of five crop groups (i.e., fruits, vegetables, cereals, pulses/oil crops, and sugar crops). When comparing the effect of individual nutrients on different crop groups, we found that N



Fig. 2 Changes in the nutritional quality of food crops with fertilizer application. a The location of different fieldbased experiments used in the meta-analysis. b Relative contribution of type/combination(s) of plant nutrients in improving the nutritional quality of food crops, and c responses of different nutritional quality traits to fertilizer application in fruits, vegetables, cereals, pulses/oil crops, and sugar crops. Colored dots represent the mean effect sizes with 95% confidence intervals (CIs). Mean values < 0 indicate a negative effect, while mean values > 0 indicate a positive effect (significant effect, P < 0.05, if 95% CIs did not overlap 0). The numbers (n)at the upper side of the whiskers indicate the data records for each group. The mean effect size is converted into the percentage change (%).



performed well in promoting protein accumulation in cereals, pulses/oil crops, and vegetables; K increased carbohydrate and total soluble solid concentrations in fruits; Mg increased carbohydrate accumulation in vegetables and minerals in fruits; and S increased oil accumulation in pulses/ oil crops. Notably, N fertilizers can also alter biological  $N_2$ 



fixation in pulses/legumes depending on the type and rate of applied N, soil conditions, and plant species (Herridge et al. 2008). In general, micronutrients promoted the nutritional quality of different crop groups. Although less nutrient dense than most chemical fertilizers, the treatment with organic source(s) significantly improved most crop quality traits with the exception of accumulation of minerals in fruits and cereals and total soluble solids in sugar crops. Importantly, nearly all crops require the application of multiple nutrients (Marschner 2012; Brown et al. 2021); thus, two combined fertilizer practices N + P + K + organic amendment(s) and N + P + K frequently had greater positive effects on food nutritional quality than other, less comprehensive fertilizer treatments, such as applying only a single nutrient, e.g., P or K, except for increasing total soluble solids in sugar crops and vegetables (Fig. 3).

Fig. 3 Possible interactions of type/combination(s) of fertilizer inputs in increasing the nutritional quality of food crops. Changes in concentrations of a carbohydrates, b proteins, c oils, d vitamin C, e mineral nutrients, and f total soluble solids in the edible portions of different plant groups with different type/ combination(s) of fertilizer application. Colored dots represent the mean effect sizes with 95% confidence intervals (CIs). Mean values < 0 indicate a negative effect, while mean values > 0 indicate a positive effect (significant effect, P < 0.05, if 95% CIs did not overlap 0). The numbers (n) on the right side of the whiskers indicate the data records for each group.

Carbohydrate (referring to soluble sugars and starch) concentrations were, on average, increased by 13.1% (11.2-15.4%; n = 1119) with fertilizer application (Fig. 3a). However, N application reduced carbohydrate concentrations in fruits, probably due to the "dilution effect" resulting from yield (fresh weight) increase, while P application had no impact. However, N supplemented with organic sources and combination of N or P with K all gave rise to increases in carbohydrate concentration. Combined application of N, P, K, and/or organic sources further increased carbohydrate concentrations in fruits as well as in cereals. Importantly, micronutrient(s) and organic source(s) had comparable impacts as N + P + K in fruits and vegetables. In vegetables, either individual N, P, or their combined application had no impact, but K addition led to positive effects. The sole application of Mg and organic source(s) had surprisingly larger impacts than N + P + K in vegetables. The larger response



to Mg application can be because Mg is often a latently deficient nutrient in the soil (Ishfaq et al. 2022a). In cereals, carbohydrate concentrations did not change significantly with P application; however, combined application of P with N or K promoted carbohydrate concentration.

Protein concentrations were significantly (P < 0.05) increased by 12.5% (11.0–14.2%; n = 1181) across all crop plants in response to fertilizer application (Fig. 3b). The largest increase in protein concentrations was found with the application of N + P + K to vegetables and cereals, and with N + P + K + organic source(s) to pulses/oil crops. The next most efficient treatment was N in these three plant groups, comparable in effect to the most effective fertilization treatment. On the other hand, the P + K treatment did not have effects on protein concentration in any crop group. Mg (for vegetables and cereals), K (for cereals), and S (for pulses/oil crops) did not, either.

Oil concentrations were increased by fertilization to a lesser extent than carbohydrate and protein concentrations. The average increase was 4.1% (1.5–6.4%; n = 431) in pulses/oil crops and cereals (Fig. 3c). Oil concentrations increased by 11.6% in pulses/oil crops with the application of S, which might be due to the contribution of S to oil formation, especially on S-poor soils (Malhi et al. 2007; Egesel et al. 2009; Raza et al. 2018; Geng et al. 2021). However, individual application of N, P, K, or Ca had no impact on oil concentration in pulses/oil crops. Combined application of N with other nutrients enabled positive results. In cereals (mainly maize), separate application of N or P increased oil concentration; however, combined application of N and P did not, possibly due to improper ratios, complicated interactions, or insufficient number of data. The N + P + K treatment was significantly more efficient than N or P treatments.

Vitamin C concentrations were increased with fertilizer application by 15.3% (12.5–19.0%; n = 929) on average across all crop species (Fig. 3d). The treatments of sole K, Mg, or organic source(s) and various combinations with K significantly increased vitamin C concentration (P < 0.05) in fruits although N, P, Ca, or micronutrient(s) did not. In vegetables, the largest increase in vitamin C concentration was found with the application of N + P + K, followed by N + P + K + organic source(s), organic source(s), N, Mg, K, and micronutrient(s) application. Linear regression analyses indicated that higher levels of sole N application  $(> 400 \text{ kg ha}^{-1})$  negatively influenced vitamin C concentrations (Fig. 4a). However, the higher application of organic sources increased vitamin C concentrations (Fig. 4d). There was no significant increase with Ca application, although positive effects of Ca on vitamin C concentrations have been observed in some studies (Marschner 2012; Islam et al. 2016).

Crops provide large amounts of various mineral nutrients essential for human health (Welch et al. 2013; Dobermann

et al. 2022; Assunção et al. 2022), among which K, Ca, Mg, Zn and Fe in the edible part of plant were grouped as single quality trait "mineral nutrients" in this study. Fertilizer application increased the concentration of these mineral nutrients, on average, by 18.9% (14.7–23.8%; n = 726) (Fig. 3e). Most treatments showed positive impacts, with the largest increase with the application of N + P + K + organic source(s) or N + P + K in fruits, vegetables, and cereals. The treatment of sole N, P, K, micronutrients, and combinations of N with K or P increased mineral concentration in all crops studied. We interpret the comparatively smaller concentration increase of mineral nutrients with sole N application as a "dilution effect" whereby an increase in mineral accumulation in produce is partly offset by total yield increase, as exemplified for vegetables (Fig. 4a).

The analysis showed that TSS concentration was increased, on average, by 5.0% (3.9–6.2%; n = 733) in fruits, vegetables, and sugar crops, although increases in TSS concentration varied widely among fertilizer types and crop species groups (Fig. 3f). In fruits, the TSS concentration was increased significantly to a larger extent by the application of K, P + K, Ca, and Mg. Combined application of N with K, P, or organic source(s) also led to significant positive results but N and N + P had no effect. The N + P + K treatment caused no change in contrast to positive effects by application of N or organic source(s) in vegetables. N + P + K, N + P + K + organic source(s), and organic source(s) even reduced TSS accumulation in sugar crops based on the limited data sets.

As noted above, N + P + K and particularly, N + P + K + Korganic amendment(s) frequently improved the quality traits to the greatest extent (on average by 16.1%; 11.7-21.6%). To better assess the contribution of organic amendments to quality improvement, we further classified the available data based on the type of organic amendments and specific substitution ratios (replacement of inorganic NPK with organic amendments). The nutritional quality of food crops was increased by 22.8% when inorganic N + P + K was applied with organic fertilizers, 21.9% with farmyard manure (FYM) + green manuring, 15.1% with crop residues, 14.7% with poultry manure, 13.8% with vermicompost, 11.6% with FYM, 7.2% with sawdust, and 7.0% with biofertilizer application, compared to control treatments (Fig. 5a). Notably, sawdust or biofertilizer application showed smaller quality improvement than sole NPK application (Fig. 2b). We set four categories on the basis of the substitution of inorganic NPK by organic sources as low (< 25% organic sources), moderate (25-50% organic sources), high (> 50% organic sources), and additional (recommended doses of inorganic fertilizers + additional organic sources). As shown in Fig. 5b, the low and high substitution of inorganic NPK by organic source(s) contributed moderately to the nutritional quality of crops while moderate substitution and applying



**Fig. 4** Changes in the nutritional quality of vegetables with fertilizer application rates. **a** The relationship between the  $\ln RRs$  of carbohydrates (y = 1.411e-005x + 0.01; P = 0.920), proteins (y = 0.000144x + 0.056; P = 0.730), vitamin C (y = -0.00052x + 0.311; P = 0.025), and mineral nutrients (y = -0.00041x + 0.391; P = 0.040) in the edible portions of vegetables with sole N application rates. **b** The relationship between the  $\ln RRs$  of carbohydrates (y = -1.411e-005x + 0.151; P = 0.894) and vitamin C (y = -0.0003227x + 0.252; P = 0.008) in vegetables with K application rates. **c** The relation-

organic source(s) in addition to the recommended doses of inorganic fertilizer contributed greater.

# 3.3 Effects of site-specific covariates on quality improvement by fertilizer application

Climate and soil conditions affect fertilizer use efficiency (Dobermann et al. 2022; Ishfaq et al. 2022b). According to collected data about climatic zones, the nutritional quality of crop products was improved by 11.4% (10.3–12.6%; n = 5363) by fertilizer application, without significant differentiation across highlands, subtropical, arid and semi-arid, temperate, and tropical regions (Fig. 5c). The response of the nutritional quality of crops to fertilizer application varied with soil texture; silt loam (19.1%) and sandy loam (15.9%) allowed significantly greater quality improvement from fertilizer application than sandy soils (6.6%) (Fig. 5d). Fertilizer did not significantly affect crop

ship between the ln*RRs* of carbohydrates (y = 0.0003360x + 0.119; P = 0.507) and vitamin C (y = 0.0004621x + 0.079; P = 0.303) in vegetables with Mg application rates. **d** The relationship between carbohydrates (y = 0.0008028x + 0.085; P = 0.191), proteins (y = 0.0009593x + 0.216; P = 0.667), vitamin C (y = 0.01318x + 0.02665; P = 0.001), and mineral nutrients (y = 0.01040x + 0.3155; P = 0.005) ln*RRs* in the edible portions of vegetables with varying application rates of organic sources. Where ln*RR* refers to the log of the response ratio (calculated in Section 2.3).

quality on oxisols and anthrosols, but fertilizer effects were significantly positive on all other soil orders, with the greatest response of fertilizers on alfisols and histosols (Fig. S7a). Crop nutritional quality was increased by 11.7% (10.3–13.2%; n = 3946) by fertilizer application across studies with soil organic matter (SOM) reported, with the largest increase of 16.6% at SOM 2.5-5%. Fertilizer effects on crop produce quality were greater at SOM 2.5-5% and 1-2.5% (12.1%) than at SOM < 0.5% (6.1%). The remaining two effective ranges were SOM 0.5-1%(11.1%) and > 5% (8.3%) (Fig. 5e). Soil pH is an important predictor of the availability of applied nutrients to plants (Marschner 2012; Husson 2013). In studies reporting soil pH, the nutritional quality of crops was increased by 12.2% (10.8–13.6%; n = 4040) by fertilizer application, and the positive effect was found at pH 4.5-8.5 with no effect in highly acidic (pH < 4.5) or alkaline (pH > 8.5) soils (Fig. 5f). Crops responded positively to fertilizer





**Fig. 5** Effects of site-specific covariates on the increase in the nutritional quality of food crops with fertilizer application. Variations in the nutritional quality of food crops with **a** the type of organic sources applied with mineral fertilizers and **b** the amount of inorganic fertilizers (NPK) substituted with organic source(s). Variations in the increase in crop nutritional quality with fertilizer application among various **c** climatic conditions, and different types/levels of soil **d** tex-

ture, **e** organic matter (%), **f** pH, **g** total nitrogen (mg kg<sup>-1</sup>), **h** Olsenphosphorus (mg kg<sup>-1</sup>), and **i** exchangeable potassium (mg kg<sup>-1</sup>). Colored dots/bar graphs represent the mean effect sizes with 95% confidence intervals (CIs). Mean values < 0 indicate a negative effect, while mean values > 0 indicate a positive effect (significant effect, *P* < 0.05, if 95% CIs did not overlap 0). The numbers (*n*) on the right side of the whiskers indicate the data records for each group.

application at different levels of soil total N, Olsen-P, and Ex-K (Fig. 5g–i). Soils containing 60–125 mg N kg<sup>-1</sup> total N had greater quality improvement (27.7%) upon fertilizer application than those with more than 500 mg N kg<sup>-1</sup> total N (10.3%) (Fig. 5g). Soils with 7–14 mg P kg<sup>-1</sup> showed greater quality improvement (16.4%) by fertilizer application than those with more than 80 mg P kg<sup>-1</sup> (6.5%) (Fig. 5h). In the case of Ex-K, the largest effect was derived from soils with 80–120 mg Ex-K kg<sup>-1</sup>, with the lowest and significant effect when Ex-K was less than 40 mg kg<sup>-1</sup> (Fig. 5i).

The scatter plot matrix indicated significant relationship in most of the site-specific covariates in increasing the nutritional quality of food crops by fertilizer application (Fig. S8). We ranked these site-specific covariates according to their relative importance for predicting quality improvement. Results showed that soil pH and Ex-K were the most important variables while texture and total N were the least important variables in improving the nutritional quality of food crops with fertilizer application (Fig. S9).

Different continents have distinct natural, agricultural, and economic conditions affecting crop breeding, soil fertility, fertilizer consumption, and crop yields (Welch et al. 2013; Muthayya et al. 2013; Bouis and Saltzman 2017). In a continent-wise comparison (n = 5353), we found that the increase in the nutritional quality of crops with applied fertilizers was greatest in Africa (29.8%; [19.7–43.1%]), and significantly lower in Asia (12.8%; [10.6–15.4%]; excluding China) and Europe (12.3%; [9.3–15.6%]). As a particular country that contributes significantly to



**Fig. 6** Variations in the nutritional quality of food crops with fertilizer application among different continents. **a** Cross-continent responsiveness in the increase in the nutritional quality of food crops with fertilizer application. A comparison of China and sub-Saharan Africa in terms of soil **b** organic matter, **c** total nitrogen, **d** Olsenphosphorus, and **e** exchangeable potassium concentrations. In panel **a**, colored bar graphs represent the mean effect sizes with 95% con-

fidence intervals (CIs) and the numbers (*n*) on the right side of the whiskers indicate the data records for each group. In panels **b**–**e**, box graphs show the geometric mean while the whiskers represent the maximal/minimal values. Asterisks indicate significant differences at \*P < 0.05 and \*\*\*P < 0.001, according to the Mann-Whitney test. Where ns refers to non-significant.

fertilizer consumption and crop production worldwide, China had the least increase in crop nutritional quality in response to fertilizer (9.9%; [8.5–11.2%]) (Fig. 6a). We next analyzed potential soil factors influencing fertilizer responses in Africa and China, two regions where future crop production is of paramount importance to ensure food and nutritional security. There was no clear difference in the SOM (Fig. 6b) and soil total N (Fig. 6c); however, soils contained significantly lower concentrations of available P (P < 0.0001) and K (P < 0.05) in Africa. The comparatively higher responsiveness of fertilizer in Africa as compared to China is most likely due to the high prevalence of nutrient-poor soils in Africa and the low prevalence in China (Fig. 6d and e).

# 3.4 Differential effects of fertilizer application on crop yield

Quality traits are closely associated with crop yield due to internal biological and physiological crosstalk during crop development (Scheelbeek et al. 2018; Lu and Zhu 2022; Assunção et al. 2022). Overall, yield significantly (P < 0.05) increased, by 30.9% (28.2–33.7%; n = 2496), with fertilizer application (Fig. 7 and Fig. S6b). The yield increase varied with fertilizer types and crop species groups. Sole application of N, P, K, or Mg significantly increased yields of the five different groups of crops, and micronutrients and organic amendments did so, too. Thereby, N application led to a larger effect than application of P, K, Mg, Ca, or S. Application of micronutrients in fruits led to an increase in yield similar to that of N + P + K application. Out of various combined fertilizer applications, the largest increase in yield was obtained with the application of N + P + K + organicamendment(s) or N + P + K across crop groups. Notably, N + P + K (102.4%; [69.7–144.3%) and N + P + K + organic amendment(s) (94.7%; 64.5-133.2%) showed significantly greater impact on vegetable yield than other treatments. No effect was found for N + organic amendments in vegetables and Ca or S in pulses/oil crops.





**Fig. 7** The contribution of the sole and combined application of fertilizers in increasing the yield of fruits, vegetables, cereals, pulses/oil crops, and sugar crops. Colored dots represent the mean effect sizes with 95% confidence intervals (CIs). Mean values < 0 indicate a negative effect, while mean values > 0 indicate a positive effect (significant effect, P < 0.05, if 95% CIs did not overlap 0). The numbers (*n*) on the right side of the whiskers indicate the data records for each group.

Fertilizer application improved crop yield significantly by 34.7% (31.5–38.3%; n = 2220) across different climatic conditions (Fig. 8a). The mean effect was largest (40.7%) under subtropical conditions, and significantly lower (27.1%) under temperate conditions, with the response in other climate zones intermediate. In studies recording soil texture, fertilizer application increased yield by 31.4% (27.9–35.0%; n = 1737). The increases in yield with fertilizer application were greatest (60.9%) when crops were grown in silt loam, and clay (18.4%) and sandy (15.9%) soils gave rise to significantly less impact than silt loam (Fig. 8b). Fertilizer effects decreased in the order alfisols (66.6%), ultisols (58.6%), histosols (48.5%), and inceptisols (45.0%), but were significantly greater than on soil with weak response, such as fluvisols (12.0%), mollisols (10.2%), and vertisols (4.2%)



(Fig. S7b). In studies reporting SOM, yield increase of all crops upon fertilizer application was 30.4% (27.2–33.9%: n = 1916), with larger increases at SOM 2.5–5% and lower increases at SOM < 0.5% and > 5% (Fig. 8c). In studies reporting soil pH, fertilizer additions increased yield by 32.7% (29.7–35.9%; n = 2026) across all crops, and crops were more responsive on neutral soils (pH 6.5-7.5) in comparison with alkaline (pH > 8.5) soils (Fig. 8d). In studies reporting total soil N concentration, on average, yield was increased by 37.5% (33.5–42.0%; n = 1577) by fertilizer application. The increase in yield upon fertilizer application was greater at medium soil N concentrations such as  $250-500 \text{ mg kg}^{-1}$ ,  $125-250 \text{ mg kg}^{-1}$ , and  $60-125 \text{ mg kg}^{-1}$ , and least at higher and lower soil N concentrations (Fig. 8e). In studies reporting available P in soils, the increase in yield with fertilizer application at available P concentration of 7–14 mg kg<sup>-1</sup> (49.2%) and < 7 mg kg<sup>-1</sup> (37.9%) was significantly greater than at 14–80 kg<sup>-1</sup> (21.9%) and > 80 mg kg<sup>-1</sup> (15.2%) (Fig. 8f). In P-depleted soils, P fertilizer application can be less effective due to the strong P binding capacity (Lambers 2022). In studies reporting soil Ex-K, the increase in yield following the application of fertilizers was 20.1% at > 160 mg kg<sup>-1</sup> soil Ex-K, significantly higher than zero, but it was significantly lower than the grand mean (29.9%), while responses greater than the grand mean were recorded at 40–80 mg kg<sup>-1</sup> (40.6%) and 80–120 mg kg<sup>-1</sup> (36.0%) soil Ex-K (Fig. 8g). The scatterplot matrix indicated significant relationship in most of these site-specific covariates in increasing the yield of food crops by fertilizer application (Fig. S10). The relative importance of the site-specific covariates is shown in Fig. S11, suggesting that soil total N was one of the most important variables while soil pH and Ex-K were the least important variables in improving the yield of food crops with fertilizer application.

### 3.5 Correlative effects of fertilizer application on crop yield and nutritional quality

Linear regressions were performed to evaluate correlative properties of crop yield increase and nutritional quality increase due to fertilization. There were strong positive correlations between the fertilizer responses of carbohydrate concentrations and yield in cereals, vegetables, and fruits (Fig. 9a); protein concentrations and yield in cereals and pulses/oil crops (Fig. 9b); oil concentrations and yield in cereals and pulses/oil crops (Fig. 9c); vitamin C concentrations and yield in fruits (Fig. 9d); and mineral nutrients concentrations and yield in fruits, vegetables, and cereals (Fig. 9e). There was negative correlation between protein concentrations and yield in vegetables (Fig. 9b), no relationship was found between vitamin C concentrations and yield in vegetables (Fig. 9d), and TSS and yield in fruits, vegetables, and sugar crops (Fig. 9f). General positive relationships

Fig. 8 Effects of site-specific covariates on the increase in yield of food crops with fertilizer application. Effects of a climatic conditions, and soil b texture, **c** organic matter (%), **d** pH, e total nitrogen (mg kg-). **f** Olsen-phosphorus (mg kg<sup>-1</sup>), and  $\mathbf{g}$  exchangeable potassium  $(mg kg^{-1})$  on the increase in vield of crops with fertilizer application. Colored bar graphs represent the mean effect sizes with 95% confidence intervals (CIs). Mean values < 0 indicate a negative effect, while mean values > 0 indicate a positive effect (significant effect, P <0.05, if 95% CIs did not overlap 0). The numbers (n) on the right side of the whiskers indicate the data records for each group.



between the fertilizer responses of nutritional quality and yield of food crops suggested that nutritional quality and yield can be improved in tandem with appropriate fertilizer applications (Fig. 9 and Table S2).

# **4** Discussion

This meta-analysis synthesizes information from 551 field experiment-based articles and highlights that fertilizer application increases the yield and nutritional quality of crop plants in a nutrient- and crop-dependent manner. The results provide insights into the effects of site-specific covariates related to soils and climate on the increase in yield and nutritional value of food crops by fertilizer application, thereby informing on the likely effectiveness of fertilizer management practices in a given production environment, supporting the development of strategies to obtain higher yields and better quality products.

The findings show that nutrient interactions make important contributions to increasing the nutritional quality of produce. Sole application of N or P fertilizers fails to increase the concentration of carbohydrates, oil, vitamin C, or TSS in many crop groups; however, combined application of K with N, P, or both has the greatest positive effects on the nutritional quality of crops (Fig. 3). N + P + K and N + P+ K + organic amendments are the most effective nutrient management solution for increasing the concentrations of key quality components (i.e., carbohydrates, proteins, oil, vitamin C, lycopene/carotenoids, mineral nutrients, and TSS) of food crops (Figs. 2 and 3). We speculate that the greater increases in yield and nutritional quality obtained by combined application of inorganic fertilizers and organic amendment(s) are due to four main reasons. Firstly, the application of organic amendment(s) in fertilizer programs can improve the physicochemical properties, microbiome diversity, and eco-functionality of the soil, thus favoring root growth and enhancing the availability of nutrients for plant roots (Tiessen et al. 1994; Bonanomi et al. 2020; Hoffland et al. 2020; Kravchenko et al. 2021; Ling et al. 2022). Secondly, the additional supply of multiple nutrients, i.e., Ca, Mg, Zn, and Fe from organic sources may contribute to improving the nutritional quality of agricultural produce (Gil





**Fig. 9** Relationships between yield and nutritional quality of different crop groups driven by fertilizer application. Linear regressions indicate positive relationships between yield and quality traits **a** carbohydrates in fruits ( $R^2 = 0.4317$ ; P < 0.001), vegetables ( $R^2 = 0.3967$ ; P < 0.001) and cereals ( $R^2 = 0.6492$ ; P < 0.001), **b** proteins in vegetables ( $R^2 = 0.1473$ ; P < 0.001), cereals ( $R^2 = 0.3728$ ; P < 0.001), pulses/oil crops ( $R^2 = 0.6413$ ; P < 0.001), and **c** oil concentrations in pulses/oil crops ( $R^2 = 0.3281$ ; P < 0.001) and cereals ( $R^2 = 0.6926$ ;

P < 0.001). Positive correlations between yield and **d** vitamin C in fruits ( $R^2 = 0.4695$ ; P < 0.001) and vegetables ( $R^2 = 0.3108$ ; P < 0.001), **e** mineral nutrients in fruits ( $R^2 = 0.2127$ ; P < 0.001), vegetables ( $R^2 = 0.5627$ ; P < 0.001) and cereals ( $R^2 = 0.1288$ ; P < 0.001), and **f** total soluble solids in fruits ( $R^2 = 0.1315$ ; P < 0.001), vegetables ( $R^2 = 0.4766$ ; P < 0.001), and sugar crops ( $R^2 = 0.1364$ ; P < 0.045). Where ln*RR* refers to the log of the response ratio (calculated in Section 2.3).

et al. 2008; Singh et al. 2019; Henneron et al. 2020). Thirdly, the nutrient releasing capacity of the organic amendment(s) is usually slow and long-lasting and nutrients become available only after mineralization, thus ensuring continuous supply of nutrients throughout the growing season (Torn et al. 1997; Kan et al. 2022). Fourthly, at any given site, any nutrient can be the limiting nutrient for either yield or quality as indicated by Liebig's law of the minimum. Thus, the larger number of nutrients applied by combined fertilizers increases the odds of fulfilling the need for the most limiting nutrient (Tiessen et al. 1994; Singh et al. 2019).

The replacement of 25–50% of the inorganic NPK fertilizers by organic amendment(s) could attain maximum nutritional quality of food crops. The substitution of 25% mineral N fertilizers by organic amendment(s) would circumvent approximately 26.93 million tonnes of global dependence on synthetic N inputs (FAOSTAT 2022), and in addition benefit soil eco-functionality (Tiessen et al. 1994; Ling et al. 2022). High replacement of inorganic NPK fertilizers by organic sources (> 50%), however, generally results in a decrease in the nutritional quality of food crops (Fig. 5b), which might be due to the lower immediate availability of mineral nutrients in organic sources than inorganic fertilizers and a short-term decline in soil fertility (Zhang et al. 2019a, b, c, d).

Obtaining higher yield and better quality while maintaining long-term soil fertility is a key target of crop production although the relationships between yield and quality remain unclear. Some previous studies have reported that aspects of nutritional quality were negatively related to yield due to the "dilution effect," variety/genotypic variations, or other management practices (Correndo et al. 2021; Si et al. 2022; Miner et al. 2022), but this is not always observed (White et al. 2009; Assefa et al. 2018; Pan et al. 2020; Guangxin et al. 2022). Our meta-analysis is based on a wide set of nutrient management practices, and overall, positive relationships between yield and most of the quality traits were observed when the yield was increased through fertilizer application (Fig. 9 and Table S2).

Vegetables showed the greatest increase in yield and nutritional quality in response to fertilizer application (Fig. 2c and Fig. 7). This might be due to greater fertilizer requirements of many vegetable crops in comparison to other crops (Ficiciyan et al. 2021; Sánchez et al. 2021). Another possible reason is that vegetables are often short duration crops with a larger harvest index than many other crops, suggesting that fertilizer applications are more likely to contribute to the development of their edible organs and related quality traits (Shi et al. 2010; Ficiciyan et al. 2021). Finally, vegetables like leguminous plants can be very efficient in nutrient acquisition due to their root system architecture (Shi et al. 2010; Ishfaq et al. 2021b). These interpretations suggest directions for future research to understand the physiological mechanisms behind the variation in responses of yield and nutritional quality to fertilizers among different plant groups.

Environmental conditions change the physicochemical properties of soil and plant performance substantially (Lesk et al. 2021; Ishfaq et al. 2022b). The effects of site-specific climatic conditions and seven important edaphic factors, namely, soil texture and order, SOM, pH, total N, Olsen-P, and Ex-K, on the yield and nutritional quality of food crops were evaluated to identify the environmental conditions influencing the impact of fertilizer addition on improving yield and nutritional quality of food crops. In general, our results show that crops cultivated in regions with higher temperatures, poor SOM, extremes in pH, and predominantly in sandy soils might be prone to smaller increases in yield and nutritional quality with fertilizer applications (Figs. 5 and 8). Highlands contained a higher level of SOM (Fig. 10), which may improve the soil eco-functionality and availability of mineral nutrients for crops and, thereby, lead to larger response to applied fertilizers (Solomon et al. 2002; Lal 2004; Lichter et al. 2008). Among soil properties, optimal levels of SOM, N, P, and K can precondition the improvement of yield and nutritional quality of food crops, and the application of fertilizers has larger effects on the yield and nutritional quality of crops grown in these soils (Figs. 5 and 8). Under extreme conditions, the limited increase in yield and nutritional quality of crops grown on soils with low SOM (< 0.5%) underscores the consequences of the low



Fig. 10 Changes in soil organic matter under different climatic conditions. The numbers (n) at the lower side of the whiskers indicate the data records for each group.

nutrient buffering capacity of these soils (Torn et al. 1997; Mäder et al. 2002; Schmidt et al. 2011). The improvement in crop quality was lowest at the lowest level of soil Ex-K (< 40 mg kg<sup>-1</sup>) (Fig. 5i), possibly because the depleted clay mineral needs to be replenished before a plant response occurs (Wakeel and Ishfaq 2022). The non-significant responses of nutritional quality to fertilizer applications in highly acidic (pH < 4.5) and alkaline soils (pH > 8.5) is possibly due to the effects of exchangeable cations: H<sup>+</sup>, Fe<sup>3+</sup>, and Al<sup>3+</sup> in acidic soils and Na<sup>+</sup> and Ca<sup>2+</sup> in alkaline soils, which can inhibit root growth, compete with nutrient cations applied in fertilizers, and alter the availability of certain nutrients by forming sparingly soluble oxides, phosphates, or carbonates (Guo et al. 2010; Marchner 2012; Husson 2013). Globally, approximately 950 million hectares of ice-free land are acidic (Uexküll and Mutert, 1995), and more than 833 million hectares are salt affected (FAO 2021b). Both conditions are potentially limiting agricultural productivity, and a larger dataset derived from these types of soils is required to more precisely quantify the contribution of fertilizers and other management practices (i.e., liming, manure, and gypsum application) to world food production.

The increase in the nutritional quality of food crops with fertilizer application was greatest in Africa, compared to other regions of the world such as Asia (excluding China), Europe, America, and China (Fig. 6a). This underscores the importance of fertilizers to boost food and nutritional security in Africa. A closer look at the data shows no clear difference in SOM (Fig. 6b) and total N (Fig. 6c) between Africa and China, but the soils of Africa had significantly less phytoavailable P and K (Fig. 6d and e). Nutrient deficiency is widespread in the soils of sub-Saharan Africa (van Ittersum et al. 2016; Kihara et al. 2017; Ten Berge et al. 2019; Manzeke et al. 2019; Gashu et al. 2021; Kihara et al. 2020), and crop production on nutrient-poor soils is generally more responsive to the application of fertilizers. By contrast, as Chinese farmers have developed intensive cultivation systems, increasing amounts of fertilizers have been applied in recent decades and this enrichment of the soil may have contributed to a lower responsiveness to fertilizer (Zhang et al. 2015a, b, c, d, e; Cui et al. 2018; FAOSTAT 2022; Ishfaq et al. 2022a; Chen et al. 2022a, b).

The increase in the nutritional quality of food crops with fertilizer application can minimize nutrition-related risks, especially in the regions where staple food is produced and consumed locally with little applied fertilizers (Cakmak 2008; Manzeke et al. 2012; Ishfaq et al. 2021a; Assunção et al. 2022). Although combined nutrient management practices (organic and inorganic) have been well practiced by some smallholder farmers (Zhang et al. 2019a, b, c, d), the availability of organic fertilizers/amendments needs to be ensured particularly in nutrient-deficient regions, to produce nutritious food. Providing incentives to farmers



to adopt better soil and crop management practices (i.e., organic fertilizers or other organic amendments, legumebased rotation, and liming) might ensure the production of nutritious food and contribute to the availability of sustainable, healthy diets.

Currently, fertilizer application improves crop nutritional quality by 11.9% and yield by 30.9% on average; combined application of NPK and organic amendments can further boost crop nutritional quality and yield in the future when optimal soil conditions become more prevalent, such as pH 6.5–7.5, SOM 2.5–5.0%, soil total N 60–125 mg kg<sup>-1</sup>, Olsen-P 7-80 mg kg<sup>-1</sup>, and Ex-K 40-120 mg kg<sup>-1</sup>. In our analysis, we did not assess the effects of other important management practices such as liming, legume-based rotation, and irrigation which can also affect the availability of mineral nutrients and nutritional quality of food (Navarro et al. 2010; Zhao et al. 2022; Mudare et al. 2022), and systematic literature review is suggested to quantify their contribution. Predicted effects of climate change and extreme weather events may also influence some of these results (Scheelbeek et al. 2018; Jägermeyr et al. 2021; Lesk et al. 2021; Ishfaq et al. 2022b), requiring in-depth investigations. In future studies, it will be important to assess the complex interactions of fertilization × genotypes × environmental stresses on yield and nutritional quality of food crops holistically to ensure a more sustainable global food system.

# 5 Conclusions

Fertilizer programs implemented in the past have mainly focused on improving crop yields, with little priority given to the nutritional outcomes for human health. There was a need to comprehensively quantify how different fertilization strategies contribute to accumulation of nutritionally relevant components in food crops. By analyzing 7859 data pairs from 551 field experiments, we concluded that (i) on average, fertilizer application improves crop yield by 30.9% (CI: 28.2–33.7%) and nutritional quality by 11.9% (CI: 10.7-12.1%; (ii) over all sites, N + P + K or N + P + K + organic amendment(s) is the most effective nutrient management solution for increasing the concentrations of key quality components (i.e., carbohydrates, proteins, oil, vitamin C, lycopene/carotenoids, mineral nutrients, and TSS) of food crops; (iii) vegetables are the most responsive to fertilizer application in terms of improving nutritional quality; (iv) in general, crops cultivated in regions with higher temperatures, poor SOM, extreme pH, and predominantly in sandy soils might be prone to smaller increase in nutritional quality with fertilizer applications; (v) the increase in the nutritional quality of food crops with fertilizer application is greatest in Africa, compared to other regions of the world such as Asia (excluding China), Europe, America, and China; (vi) the



nutritional quality and yield of food crops can be improved in tandem with appropriate fertilizer applications. In a nutshell, our global meta-analysis offers a useful quantitative framework to better understand the effectiveness of fertilizer management practices in a given production environment (i.e., soil properties and climatic conditions), fostering the sustainable production of nutritious and healthy diets for human consumption.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13593-023-00923-7.

Authors' contributions M. I. and X. L. were involved in conceptualization, data curation and analysis, and manuscript writing. Y. W., J. X., M. U. H., H. Y., L. L., B. H., and I. E. were involved in data collection. P. J. W., I. C., W. S. C., J. W., W. V. D. W., C. L., and F. Z. were involved in writing, review, and editing the manuscript.

**Funding** This work was supported by grants from the National Key Research and Development Program of China (2021YFD1901103) and National Natural Science Foundation of China (31972491, 32172663). We thank Dr. Xin Zhao at China Agricultural University for insightful comments and suggestions.

Data availability Supplementary material contained.

Code availability Not applicable.

#### Declarations

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests Thel authors declare no competing interests.

Ethics approval Not applicable.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

## References

- Adams DC, Gurevitch J, Rosenberg MS (1997) Resampling tests for meta-analysis of ecological data. Ecol 78:1277. https://doi.org/ 10.1890/0012-9658(1997)078[1277:RTFMAO]2.0.CO;2
- Assefa Y, Bajjalieh N, Archontoulis S, Casteel S, Davidson D, Kovacs P, Naeve S, Ciampitti IA (2018) Spatial characterization of soybean yield and quality (amino acids, oil, and protein)

for United States. Sci Rep 8:14653. https://doi.org/10.1038/ s41598-018-32895-0

- Assunção AGL, Cakmak I, Clemens S, González-Guerrero M, Nawrocki A, Thomine S (2022) Micronutrient homeostasis in plants for more sustainable agriculture and healthier human nutrition. J Exp Bot 73:1789–1799. https://doi.org/10.1093/jxb/erac014
- Bonanomi G, De FF, Zotti M, Idbella M, Cesarano G, Al-Rowaily S, Abd-ElGawad A (2020) Repeated applications of organic amendments promote beneficial microbiota, improve soil fertility and increase crop yield. Appl Soil Ecol 156:103714. https://doi.org/ 10.1016/j.apsoil.2020.103714
- Borenstein M, Hedges LV, Higgins JPT, Rothstein HR (2011) Introduction to meta-analysis. John Wiley & Sons. ISBN: 978-1-119-55835-4.
- Bouis HE, Saltzman A (2017) Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016. Glob Food Sec 12:49–58. https://doi.org/10.1016/j.gfs.2017.01.009
- Brown PH, Zhao FJ, Dobermann A (2021) What is a plant nutrient? Changing definitions to advance science and innovation in plant nutrition. Plant Soil. 476:11–23. https://doi.org/10.1016/j.gfs. 2017.01.009
- Byerlee D, Fanzo J (2019) The SDG of zero hunger 75 years on: turning full circle on agriculture and nutrition. Glob Food Sec 21:52– 59. https://doi.org/10.1016/j.gfs.2019.06.002
- Cakmak I (2008) Enrichment of cereal grains with zinc: agronomic or genetic biofortification? Plant Soil 302:1–17. https://doi.org/10. 1007/s11104-007-9466-3
- Cakmak I, Kutman UB (2018) Agronomic biofortification of cereals with zinc: a review. Eur J Soil Sci 69:172–18. https://doi.org/10. 1111/ejss.12437
- Cakmak I, McLaughlin MJ, White P (2016) Zinc for better crop production and human health. Plant Soil 411:1–4. https://doi.org/10. 1007/s11104-016-3166-9
- Chen F, Lu J, Liu D (2007) Investigation of soil fertility in citrus orchards of southern China. Better Crops 91:24–25
- Chen S, Liang Z, Webster R, Zhang G, Zhou Y, Teng H, Hu B, Arrouays D, Shi Z (2018) A high-resolution map of soil pH in China made by hybrid modelling of sparse soil data and environmental covariates and its implications for pollution. Sci Total Environ 655:273–283. https://doi.org/10.1016/j.scitotenv.2018.11.230
- Chen X, Wang Z, Muneer MA, Ma C, He D, White PJ, Li C, Zhang F (2022) Short planks in the crop nutrient barrel theory of China are changing: evidence from 15 crops in 13 provinces. Food Energ Sec 00:e389. https://doi.org/10.1002/fes3.389
- Correndo AA, Fernandez JA, Vara PPV, Ciampitti IA (2021) Do water and nitrogen management practices impact grain quality in maize? Agron 11:1851. https://doi.org/10.3390/agronomy11091851
- Cui Z, Zhang H, Chen X et al (2018) Pursuing sustainable productivity with millions of smallholder farmers. Nature 555:363–366. https://doi.org/10.1038/nature25785
- Dick CD, Thompson NM, Epplin FM, Arnall DB (2016) Managing late-season foliar nitrogen fertilization to increase grain protein for winter wheat. Agron J 108:2329–2338. https://doi.org/10. 2134/agronj2016.02.0106
- Dobermann A, Bruulsema T, Cakmak I, Gerard B, Majumdar K, McLaughlin M, Reidsma P (2022) Responsible plant nutrition: a new paradigm to support food system transformation. Glob Food Sec 33:100636. https://doi.org/10.1016/j.gfs.2022.100636
- Egesel CÖ, Gül MK, Kahrıman F (2009) Changes in yield and seed quality traits in rapeseed genotypes by sulphur fertilization. Eur Food Res Tech 229:841–841. https://doi.org/10.1007/ s00217-009-1067-3
- Eussen S, Alles M, Uijterschout L, Brus F, van der Horst-Graat J (2015) Iron intake and status of children aged 6–36 months in Europe: a systematic review. Annals Nutri Metab 66:80–92. https://doi. org/10.1159/000371357

- FAO (1996) Rome declaration on world food security and world food summit plan of action. In: World Food Summit; Rome, Italy; November 1-17.
- FAO (2019) The state of food security and nutrition in the world 2019. Safeguarding against economic slowdowns and downturns, Rome, p 239
- FAO (2021) Asia and the pacific regional overview of food security and nutrition 2020: maternal and child diets at the heart of improving nutrition. FAO, Bangkok, p 120
- FAO (2021b) Global map of salt affected soils version 1.0 https://www. fao.org/soils-portal/data-hub/soil-maps-and-databases/globalmap-of-salt-affected-soils/en/
- FAO, IFAD, UNICEF, WFP, WHO (2020) The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets. FAO, Rome.
- FAOSTAT (2022) Food and Agricultural Organization of the United Nations. (Accessed on: 29 May 2022)
- Ficiciyan AM, Loos J, Tscharntke T (2021) Similar yield benefits of hybrid, conventional, and organic tomato and sweet pepper varieties under well-watered and drought-stressed conditions. Front Sustain Food Syst 5:628537. https://doi.org/10.3389/fsufs.2021. 628537
- Gashu D, Nalivata PC, Amede T et al (2021) The nutritional quality of cereals varies geospatially in Ethiopia and Malawi. Nature 594:71–76. https://doi.org/10.1038/s41586-021-03559-3
- Geng G, Cakmak I, Ren T, Lu Z, Lu J (2021) Effect of magnesium fertilization on seed yield, seed quality, carbon assimilation and nutrient uptake of rapeseed plants. Field Crops Res 264:108082. https://doi.org/10.1016/j.fcr.2021.108082
- Gil MV, Carballo MT, Calvo LF (2008) Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients. Waste Manag 28:1432–1440. https://doi.org/10. 1016/j.wasman.2007.05.009
- Global Panel (2016) Food systems and diets: facing the challenges of the 21<sup>st</sup> century. Global Panel on Agriculture and Food Systems for Nutrition. London, UK. http://glopan.org/sites/default/files/ ForesightReport.pdf
- Gödecke T, Stein AJ, Qaim M (2018) The global burden of chronic and hidden hunger: trends and determinants. Glob Food Sec 17:21–29. https://doi.org/10.1016/j.gfs.2020.100480
- Grotz N, Guerinot ML (2006) Molecular aspects of Cu, Fe and Zn homeostasis in plants. Biochimica et Biophysica Acta 1763:595– 608. https://doi.org/10.1016/j.bbamcr.2006.05.014
- Guangxin Z, Liu S, Dong Y, Liao Y, Han J (2022) A nitrogen fertilizer strategy for simultaneously increasing wheat grain yield and protein content: mixed application of controlled-release urea and normal urea. Field Crops Res 277:108405. https://doi.org/ 10.1016/j.fcr.2021.108405
- Guo JH, Liu XJ, Zhang Y et al (2010) Significant acidification in major Chinese croplands. Science 327:1008–1010. https://doi.org/10. 1126/science.1182570
- Han W, Chen Y, Fang-Jie Z, Tang L, Jiang R, Zhang F (2011) Floral, climatic and soil pH controls on leaf ash content in China's terrestrial plants. Global Ecol Biogeograph 21:376–382. https://doi. org/10.1111/j.1466-8238.2011.00677.x
- Hedges LV, Gurevitch J, Curtis PS (1999) The meta-analysis of response ratios in experimental ecology. Ecol 80:1150–1156. https://doi.org/10.2307/177062
- Heidkamp RA, Heidkamp RA, Piwoz E et al (2021) Mobilising evidence, data, and resources to achieve global maternal and child undernutrition targets and the Sustainable Development Goals: an agenda for action. Lancet 397:1400–1418. https://doi.org/10. 1016/S0140-6736(21)00568-7
- Henneron L, Kardol P, Wardle DA, Camille C, Fontaine S (2020) Rhizosphere control of soil nitrogen cycling: a key component of



plant economic strategies. New Phytol 228:1269–1282. https:// doi.org/10.1111/nph.16760

- Herridge DF, Peoples MB, Boddey RM (2008) Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil 311(1-2):1-18. https://doi.org/10.1007/s11104-008-9668-3
- Hoffland E, Kuyper TW, Comans RMJ, Creamer RE (2020) Eco-functionality of organic matter in soils. Plant Soil 455:1–22. https:// doi.org/10.1007/s11104-020-04651-9
- Husson O (2013) Redox potential (Eh) and pH as drivers of soil/plant/ microorganism systems: a transdisciplinary overview pointing to integrative opportunities for agronomy. Plant Soil 362:389–417. https://doi.org/10.1007/s11104-012-1429-7
- Ishfaq M, Kiran A, H, Rehman, M, Farooq, Ijaz NH, F, Nadeem, I, Azeem, X, Li, A, Wakeel (2022) Foliar nutrition: potential and challenges under multifaceted agriculture. Environ Exp Bot 200:104909. https://doi.org/10.1016/j.envexpbot.2022.104909
- Ishfaq M, Wakeel A, Shahzad MN, Kiran A, Li X (2021) Severity of zinc and iron malnutrition linked to low intake through a staple crop: a case study in east-central Pakistan. Environ Geochem Health 43:4219–4233. https://doi.org/10.1007/ s10653-021-00912-3
- Ishfaq M, Wang Y, Yan M, Wang Z, Wu L, Li C, Li X (2022) Physiological essence of magnesium in plants and its widespread deficiency in the farming system of China. Front Plant Sci 13:802274. https://doi.org/10.3389/fpls.2022.802274
- Ishfaq M, Zhong Y, Wang Y, Li X (2021) Magnesium limitation leads to transcriptional down-tuning of auxin synthesis, transport, and signaling in the tomato root. Front Plant Sci 12:802399. https:// doi.org/10.3389/fpls.2021.802399
- Islam MZ, Mele MA, Baek JP, Kang HM (2016) Cherry tomato qualities affected by foliar spraying with boron and calcium. Horti Environ Biotech 57:46–52. https://doi.org/10.1007/ s13580-016-0097-6
- Jägermeyr J, Müller C, Ruane AC et al (2021) Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nature Food 2:873–885. https://doi.org/10. 1038/s43016-021-00400-y
- Kan ZR, Liu WX, Liu WS, Lal R, Dang YP, Zhao X, Zhang HL (2022) Mechanisms of soil organic carbon stability and its response to no-till: a global synthesis and perspective. Glob Change Biol 28:693–710. https://doi.org/10.1111/gcb.15968
- Kihara J, Bolo P, Kinyua M, Rurinda J, Piikki K (2020) Micronutrient deficiencies in African soils and the human nutritional nexus: opportunities with staple crops. Environ Geochem Health 42:3015–3033. https://doi.org/10.1007/s10653-019-00499-w
- Kihara J, Sileshi GW, Nziguheba G, Kinyua M, Zingore S, Sommer R (2017) Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. Agron Sustain Dev 37:25. https://doi.org/10.1007/s13593-017-0431-0
- Kirkman JH, Basker A, Surapaneni A, MacGregor AN (1994) Potassium in the soils of New Zealand-a review. New Zealand J Agricul Res 37:207–227. https://doi.org/10.1080/00288233.1994.9513059
- Kravchenko AN, Zheng H, Kuzyakov Y, Robertson GP, Guber AK (2021) Belowground interplant carbon transfer promotes soil carbon gains in diverse plant communities. Soil Biol Biochem 159:108297. https://doi.org/10.1016/j.soilbio.2021.108297
- Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627. https://doi. org/10.1126/science.10973
- Lambers H (2022) Phosphorus acquisition and utilization in plants. Annu Rev Plant Biol 73:1.1-1.26. https://doi.org/10.1146/annur ev-arplant-102720-125738
- Lesk C, Coffel E, Winter J, Ray D, Zscheischler J, Seneviratne SI, Horton R (2021) Stronger temperature-moisture couplings exacerbate the impact of climate warming on global crop yields. Nature Food 2:668–691. https://doi.org/10.1038/s43016-021-00341-6

- Li XX, Wang LX, Zhang H, Du X, Jiang SW, Shen T, Zhang YP, Zeng G (2013) Seasonal variations in notification of active tuberculosis cases in China, 2005–2012. Plos One 8:e68102. https://doi.org/ 10.1371/journal.pone.0068102
- Lichter K, Govaerts B, Six J, Sayre KD, Deckers J, Dendooven L (2008) Aggregation and C and N contents of soil organic matter fractions in a permanent raised-bed planting system in the highlands of central Mexico. Plant Soil 305:237–252. https://doi.org/ 10.1007/s11104-008-9557-9
- Ling N, Wang T, Kuzyakov Y (2022) Rhizosphere bacteriome structure and functions. Nature Commun 13:836. https://doi.org/10. 1038/s41467-022-28448-9
- Lu Y, Zhu H (2022) The regulation of nutrient and flavor metabolism in tomato fruit. Vegetable Res 2. https://doi.org/10.48130/ VR-2022-0005
- Mäder P (2002) Soil fertility and biodiversity in organic farming. Science 296:1694–1697. https://doi.org/10.1126/science.1071148
- Malhi SS, Gan Y, Raney JP (2007) Yield, seed quality and sulfur uptake of Brassica oilseed crops in response to sulfur fertilization. Agron J 99:570–577. https://doi.org/10.2134/agronj2006.0269
- Manzeke GM, Mapfumo P, Mtambanengwe F, Chikowo R, Tendayi T, Cakmak I (2012) Soil fertility management effects on maize productivity and grain zinc content in smallholder farming systems of Zimbabwe. Plant Soil 361:57–69. https://doi.org/10.1007/ s11104-012-1332-2
- Manzeke MG, Mtambanengwe F, Watts MJ, Hamilton EM, Lark RM, Broadley MR, Mapfumo P (2019) Fertilizer management and soil type influence grain zinc and iron concentration under contrasting smallholder cropping systems in Zimbabwe. Sci Rep 9:6445. https://doi.org/10.1038/s41598-019-42828-0
- Marles RJ (2017) Mineral nutrient composition of vegetables, fruits and grains: the context of reports of apparent historical declines. J Food Comp Analys 56:93–103. https://doi.org/10.1016/j.jfca. 2016.11.012
- Marschner P (2012) Marschner's mineral nutrition of higher plants, third ed. Academic Press, Amsterdam, London. https://doi.org/ 10.1016/C2009-0-63043-9
- Mendenhall W, Sincich T (1995) Statistics for engineering and the sciences. Prentice-Hall, Upper Saddle River, NJ
- Menichetti G, Albert-László B (2022) Nutrient concentrations in food display universal behaviour. Nature Food 3:375–382. https://doi. org/10.1038/s43016-022-00511-0
- Miner GL, Delgado JA, Ippolito JA, Johnson JJ, Kluth DL, Stewart CE (2022) Wheat grain micronutrients and relationships with yield and protein in the U.S. Central Great Plains. Field Crops Res 279:108453. https://doi.org/10.1016/j.fcr.2022.108453
- Moher D, Liberatim A, Tetzlaff J, Altman DG, PRISMA Group (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Medicine 6:e1000097. https:// doi.org/10.1371/journal.pmed.1000097
- Moreno-Jiménez E, Orgiazzi A, Jones A, Saiz H, Aceña-Heras S, Plaza C (2021) Aridity and geochemical drivers of soil micronutrient and contaminant availability in European drylands. Europ J Soil Sci 73:e13163. https://doi.org/10.1111/ejss.13163
- Mudare S, Kanomanyanga J, Jiao X et al (2022) Yield and fertilizer benefits of maize/grain legume intercropping in China and Africa: a meta-analysis. Agron Sustain Dev 42:81. https://doi. org/10.1007/s13593-022-00816-1
- Murray CJL et al (2020) Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet 396:1223–1249. https://doi.org/10.1016/S0140-6736(20)30752-2
- Muthayya S, Rah JH, Sugimoto JD, Roos FF, Kraemer K, Black RE (2013) The global hidden hunger indices and maps: an advocacy tool for action. PLoS One 8:e67860. https://doi.org/10.1371/journal.pone.0067860



- Navarro JM, Pérez-Pérez JG, Romero P, Botía P (2010) Analysis of the changes in quality in mandarin fruit, produced by deficit irrigation treatments. Food Chem 119:1591–1596. https://doi.org/10. 1016/j.foodchem.2009.09.048
- Oldroyd GED, Leyser O (2020) A plant's diet, surviving in a variable nutrient environment. Science 368:eaba0196. https://doi.org/10. 1126/science.aba0
- Pan WL, Kidwell KK, McCracken VA, Bolton RP, Allen M (2020) Economically optimal wheat yield, protein and nitrogen use component responses to varying N supply and genotype. Front Plant Sci 10:1790. https://doi.org/10.3389/fpls.2019.01790
- Poole N, Donovan J, Erenstein O (2020) Agri-nutrition research: revisiting the contribution of maize and wheat to human nutrition and health. Food Policy 101976. https://doi.org/10.1016/j.foodpol.2020.101976
- Raza MA, Feng LY, Manaf A et al (2018) Sulphur application increases seed yield and oil content in sesame seeds under rainfed conditions. Field Crops Res 218:51–58. https://doi.org/10.1016/j.fcr.2017.12.024
- Rosenberg MS, Gurevitch J, Adams DC (2000) MetaWin: statistical software for meta-analysis: Version 2. https://www.metawinsoft.com/
- Ruel MT, Quisumbing AR, Balagamwala M (2018) Nutrition-sensitive agriculture: what have we learned so far? Glob Food Secu 17:128–153. https://doi.org/10.1016/j.gfs.2018.01.002
- Ruxton CHS, Derbyshire E, Toribio-Mateas M (2016) Role of fatty acids and micronutrients in healthy ageing: a systematic review of randomised controlled trials set in the context of European dietary surveys of older adults. J Human Nutr Dietetics 29:308– 324. https://doi.org/10.1111/jhn.12335
- Sánchez E, Pollock R, Elkner T, Butzler T, Di Gioia F (2021) Fruit yield and physicochemical quality evaluation of hybrid and grafted field-grown muskmelon in Pennsylvania. Hortic 7:69. https://doi.org/10.3390/horticulturae7040069
- Scheelbeek PFD, Bird FA, Tuomisto HL, Green R, Harris FB, Joy EJM, Chalabi Z, Allen E, Haines A, Dangour AD (2018) Effect of environmental changes on vegetable and legume yields and nutritional quality. PNAS 115:6804–6809. https://doi.org/10. 1073/pnas.1800442115
- Schmidt MWI, Torn MS, Abiven S et al (2011) Persistence of soil organic matter as an ecosystem property. Nature 478:49–56. https://doi.org/10.1038/nature10386
- Shewry P, Pellny T, Lovegrove A (2016) Is modern wheat bad for health? Nature Plants 2:16097. https://doi.org/10.1038/nplants. 2016.97
- Shi WM, Yao J, Yan F (2008) Vegetable cultivation under greenhouse conditions leads to rapid accumulation of nutrients, acidification and salinity of soils and groundwater contamination in South-Eastern China. Nutr Cycl Agroecosystems 83:73–84. https://doi. org/10.1007/s10705-008-9201-3
- Si T, Wang X, Zhou Y, Zhang K, Xie W, Yuan H, Wang Y, Sun Y (2022) Seed yield and quality responses of oilseed crops to simulated nitrogen deposition: a meta-analysis of field studies. GCB Bioenergy. 14:959–971. https://doi.org/10.1111/gcbb.12977
- Singh DK, Pandey PC, Nanda G, Gupta S (2019) Long-term effects of inorganic fertilizer and farmyard manure application on productivity, sustainability and profitability of rice-wheat system in Mollisols. Arch Agron Soil Sci 65:139–151. https://doi.org/10. 1080/03650340.2018.1491032
- Skinner C, Gattinger A, Muller A, M\u00e4der P, Flie\u00dfbach A, Stolze M, Ruser R, Niggli U (2014) Greenhouse gas fluxes from agricultural soils under organic and non-organic management-a global meta-analysis. Sci Total Environ 15:468–469. https://doi.org/10. 1016/j.scitotenv.2013.08.098
- Smith LC, Haddad L (2015) Reducing child undernutrition: past drivers and priorities for the Post-MDG Era. World Development 68:180–204. https://doi.org/10.1016/j.worlddev.2014.11.014
- Solomon D, Fritzsche F, Tekalign M, Lehmann J, Zech W (2002) Soil organic matter composition in the subhumid Ethiopian highlands

as influenced by deforestation and agricultural management. Soil Sci Soc Am J 66:68–82. https://doi.org/10.2136/sssaj2002.6800

- Sun H, Weaver CM (2020) Rise in potassium deficiency in the US population linked to agriculture practices and dietary potassium deficits. J Agricul Food Chem 68:11121–11127. https://doi.org/10.1021/acs.jafc.0c05139
- Ten Berge HFM, Hijbeek R, van Loon MP, Rurinda J, Tesfaye K, Zingore S, Craufurd P, van Heerwaarden J, Brentrup F, Schröder JJ, Boogaard HL, de Groot HLE, van Ittersum MK (2019) Maize crop nutrient input requirements for food security in sub-Saharan Africa. Glob Food Sec 23:9–21. https://doi. org/10.1016/j.gfs.2019.02.001
- Tiessen H, Cuevas E, Chacon P (1994) The role of soil organic matter in sustaining soil fertility. Nature 371:783–785. https://doi. org/10.1038/371783a0
- Torn MS, Trumbore SE, Chadwick OA, Vitousek PM, Hendricks DM (1997) Mineral control of soil organic carbon storage and turnover. Nature 389:170–173. https://doi.org/10.1038/38260
- UNICEF (2019) Children, Food and Nutrition. UNICEF. https:// www.unicef.org/wca/reports/children-food-and-nutrition
- USDA (1999) Soil taxonomy-a basic system of soil classification for making and
- interpreting soil surveys. US Gov. Print. Off. Washingt. DC. 336-337. Van Ittersum MK et al (2016) Can sub-Saharan Africa feed itself? PNAS 113:14964–14969. https://doi.org/10.1073/pnas.1610359113
- Von Uexkuell HR, Mutert E (1995) Global extent, development and economic impact of acid soils. Plant Soil 171:1–15. https://doi. org/10.1007/BF00009558
- Vural Z, Avery A, Kalogiros DI, Coneyworth LJ, Welham SJM (2020) Trace mineral intake and deficiencies in older adults living in the community and institutions: a systematic review. Nutrients 12:1072. https://doi.org/10.3390/nu12041072
- Wakeel A, M Ishfaq (2022) Potash use and dynamics in agriculture. (1<sup>st</sup> ed) Springer, Singapore. https://doi.org/10.1007/ 978-981-16-6883-8
- Welch RM, Graham RD, Cakmak I (2013) Linking agricultural production practices to improving human nutrition and health. In: ICN2 Second International Conference on Nutrition. Rome, Italy, 19-21 November 2013. Proceedings. Rome. Food and Agricultural Organization of the United Nations. https://www. fao.org/3/as574e/as574e.pdf
- Wessells KR, Brown KH (2012) Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLoS ONE 7:e50568. https://doi.org/10.1371/journal.pone.0050568
- White PJ, Bradshaw JE, Finlay M, Dale B, Ramsay G, Hammond JP, Broadley MR (2009) Relationships between yield and mineral concentrations in potato tubers. HortScience, 44:6-11. https:// doi.org/10.21273/HORTSCI.44.1.6
- White PJ, Broadley MR (2005) Biofortifying crops with essential mineral elements. Trend Plant Sci 10:586–593. https://doi.org/ 10.1016/j.tplants.2005.10.001
- White PJ, Broadley MR (2005) Historical variation in the mineral composition of edible horticultural products. J Hortic Sci Bio-technol 80:660–667. https://doi.org/10.1080/14620316.2005. 11511995
- White PJ, Broadley MR (2009) Biofortification of crops with seven mineral elements often lacking in human diets-iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytol 182:49– 84. https://doi.org/10.1111/j.1469-8137.2008.02738.x
- White PJ, Brown PH (2010) Plant nutrition for sustainable development and global health. Annal Bot 105:1073–1080. https://doi.org/10. 1093/aob/mcq085
- Wieder WR, Boehnert J, Bonan GB, Langseth MR (2014) Harmonized world soil database v1.2. ORNL DAAC. https://doi.org/10.3334/ ORNLDAAC/1247.



- Zhang X, Davidson EA, Mauzerall DL, Searchinger TD, Dumas P, Shen Y (2015) Managing nitrogen for sustainable development. Nature 3:528. https://doi.org/10.1038/nature15743
- Zhang X, Fang Q, Zhang T, Ma W, Velthof GL, Hou Y, Oenema O, Zhang F (2019) Benefits and trade-offs of replacing synthetic fertilizers by animal manures in crop production in China: a meta-analysis. Glob Change Biol 26:888–900. https://doi.org/ 10.1111/gcb.14826
- Zhao J, Chen J, Beillouin D et al (2022) Global systematic review with meta-analysis reveals yield advantage of legume-based rotations and its drivers. Nat Commun 13:4926. https://doi.org/10.1038/ s41467-022-32464-0

#### The list of articles for data retrieval

- Aboyeji CM, Dahunsi SO, Olaniyan DO, Dunsin O, Adekiya AO, Olayanju (2021) A performance and quality attributes of okra (*Abelmoschus esculentus* (L.) Moench) fruits grown under soil applied Zn-fertilizer, green biomass and poultry manure. Sci Rep 11:8291. https://doi.org/10.1038/s41598-021-87663-4
- Aglar E, Yildiz K, Ozkan Y, Ozturk B, Erdem H (2016) The effects of aminoethoxyvinylglycine and foliar zinc treatments on preharvest drops and fruit quality attributes of Jersey Mac apples. Sci Hortic 213:173–178. https://doi.org/10.1016/j.scienta.2016. 10.026
- Ahmad I, Ahmad B, Ali S, Kamran M, Qing FH, Bilegjargal B (2017) Nutrients management strategies to improve yield and quality of sugar beet in semi-arid regions. J Plant Nutr 40:2109–2115. https://doi.org/10.1080/01904167.2016.1267207
- Ahmad I, Bibi F, Ullah H, Munir T (2018) Mango fruit yield and critical quality parameters respond to foliar and soil applications of zinc and boron. Plants 7:97. https://doi.org/10.3390/plants7040097
- Akbari GA, Alahdadi I, Soufizadeh S, Parsons D (2021) Grain quality of maize cultivars as a function of planting dates, irrigation and nitrogen stress: a case study from semiarid conditions of Iran. Agriculture 11:11. https://doi.org/10.3390/agriculture11010011
- Akbari P, Ghalavand A, Modarres SAM, Alikhani MA (2011) The effect of biofertilizers, nitrogen fertilizer and farmyard manure on grain yield and seed quality of sunflower (*Helianthus annus* L.). J Agric Technol 7:173-184. ISSN 1686-9141
- Ali M, Khan I, Ali MA, Anjum SA, Ashraf U, Waqas MA (2019) Integration of organic sources with inorganic phosphorus increases hybrid maize performance and grain quality. Open Agric 4:54– 360. https://doi.org/10.1515/opag-2019-0032
- Ali N, Khan MN, Ashraf MS et al (2020) Influence of different organic manures and their combinations on productivity and quality of bread wheat. J Soil Sci Plant Nutr 20:1949–1960. https://doi.org/ 10.1007/s42729-020-00266-2
- Almaroai YA, Eissa MA (2020) Effect of biochar on yield and quality of tomato grown on a metal-contaminated soil. Sci Hortic 265:109210. https://doi.org/10.1016/j.scienta.2020. 109210
- Almendros P, Obrador A, Alvarez JM, Gonzalez D (2019) Zn-DTPA-HEDTA-EDTA application: a strategy to improve the yield and plant quality of a barley crop while reducing the n application rate. J Soil Sci Plant Nutr 19:920–934. https://doi.org/10.1007/ s42729-019-00090-3
- Al-Qurashi AD, Awad MA, Ismail SM (2015) Yield, fruit quality and nutrient uptake of "Nabbut-Ahmar" date palm grown in sandy loam soil as affected by NPK fertigation. J Plant Nutr 39:268– 278. https://doi.org/10.1080/01904167.2015.1043380
- Amadou A, Song X, Huang S, Song A, Tang Z, Dong W, Zhao S, Zhang B, Yi K, Fan F (2021) Effects of long-term organic amendment on the fertility of soil, nodulation, yield, and seed quality of

soybean in a soybean-wheat rotation system. J Soils Sediments 21:1385–1394. https://doi.org/10.1007/s11368-021-02887-1

- Amarante CVT, Steffens CA, Mafra ÁL, Albuquerque JA (2008) Yield and fruit quality of apple from conventional and organic production systems. Pesqui Agropecu Bras 43:333–340. https://doi.org/ 10.1590/S0100-204X2008000300007
- Amiri ME, Fallahi E (2007) Influence of mineral nutrients on growth, yield, berry quality, and petiole mineral nutrient concentrations of table grape. J Plant Nutr 30:463–470. https://doi.org/10.1080/ 01904160601172031
- Amiri ME, Fallahi E (2009) Impact of animal manure on soil chemistry, mineral nutrients, yield, and fruit quality in 'golden delicious' apple. J Plant Nutr 32:610–617. https://doi.org/10.1080/ 01904160802714995
- Amiri ME, Fallahi E, Golchin A (2008) Influence of foliar and ground fertilization on yield, fruit quality, and soil, leaf, and fruit mineral nutrients in apple. J Plant Nutr 31:515–525. https://doi.org/10. 1080/01904160801895035
- An JY, Meng JB, Wei ZK, Tan ZM, Liao CQ (2013) Effects of biogas fertilizer on yield and quality of navel orange. Tillage Cultiv 1:24. https://doi.org/10.13605/j.cnki.52-1065/s.2013.01.031
- An YL, Liu AL, Fan JZ, Guan Y (1989) Effects of combined application of nitrogen and phosphorus on buckwheat yield and protein content. Inner Mongolia Acad Agric Sci 5:25–26
- Anissa R, Chafik H, Mustapha S, Néji T, Mohamed BK, Ismaïl G (2009) Effect of conventional and organic production systems on the yield and quality of field tomato cultivars grown in Tunisia. J Sci Food Agric 89:2275–2282. https://doi.org/10.1002/jsfa.3720
- Anup DDP, Patel MK, Ramkrushna GI, Atanu M, Jayanta L, Ngachan SV, Juri B (2017) Impact of seven years of organic farming on soil and produce quality and crop yields in eastern Himalayas, India. Agric Ecosyst Environ 236:142–153. https://doi.org/10. 1016/j.agee.2016.09.007
- Ashraf MY, Gul A, Ashraf M, Hussain F, Ebert G (2010) Improvement in yield and quality of kinnow (*Citrus Deliciosaxcitrus Nobilis*) by potassium fertilization. J Plant Nutr 33:1625–1637. https:// doi.org/10.1080/01904167.2010.496887
- Aydin KJ, Majid G, Majid AA, Farhad H, Ali S, Amir G (2018) Response of sunflower to organic and chemical fertilizers in different drought stress conditions. Acta Agric Slov 111:271-284. https://doi.org/10.14720/aas.2018.111.2.03
- Azizi YK, Hidary M, Chaeichi S, Roham MR, Rahelea (2011) Effects of different methods of magnesium sulphate application on qualitative and quantitative yield of lentil (*Lens culinaris* Medik.) cultivars under Khorramabad climatic conditions of Iran. Res on Crops 12:103-111. ISSN: 0972-3226
- Badiger MK, Chen JM, Zhan SY (1983) Effects of potassium, sulfur and calcium on yield and quality of peanut. J Peanut Sci 3:42–44
- Bahadur L, Malhi CS, Singh Z (1998) Effect of foliar and soil applications of zinc sulphate on zinc uptake, tree size, yield, and fruit quality of mango. J Plant Nutr 21:589–600. https://doi.org/10. 1080/01904169809365426
- Bai H (2016) Effects of potassium fertilizer and syringe fertilization on soil environment and fruit yield and quality in peach orchard. Northwest A&F Uni.
- Bai H, Shi P, Guo DH, Qiao HB, Fan CH, Liu HK, Zhao CP, Li GC (2017) Effects of injection fertilizing on soil environment, fruit yield and fruit quality of peach orchard. Acta Botan Sinica Northwest China 37:541–551
- Bai H, Tao J, Shi P, Guo DH, Fan CH (2016) Topdressing fertilizer on grain yield and quality of 'chongyang red TaoGuo real before picking fruit tree and the effects of nutrition. J Northwest Agric 25:730–737
- Barłóg P, Grzebisz W, Łukowiak R (2019) The effect of potassium and sulfur fertilization on seed quality of faba bean (*Vicia faba* L.). Agron 9:209. https://doi.org/10.3390/agronomy9040209

- Basu M, Bhadoria PBS, Mahapatra SC (2008) Growth, nitrogen fixation, yield and kernel quality of peanut in response to lime, organic and inorganic fertilizer levels. Bioresour Technol 99:4675–4683. https://doi.org/10.1016/j.biortech.2007.09.078
- Behera SK, Shukla AK, Singh MV, Wanjari RH, Singh P (2015) Yield and zinc, copper, manganese and iron concentration in maize (*Zea Mays L.*) grown on vertisol as influenced by zinc application from various zinc fertilizers. J Plant Nutr 38:1544–1557. https:// doi.org/10.1080/01904167.2014.992537
- Behera UK, Sharma AR, Pandey HN (2007) Sustaining productivity of wheat-soybean cropping system through integrated nutrient management practices on the Vertisols of central India. Plant Soil 297:185–199. https://doi.org/10.1007/s11104-007-9332-3
- Bertschinger L, Mouron P, Dolega E et al (2004) Ecological apple production: a comparison of organic and integrated apple-growing. Acta Hortic 638:321-332. https://doi.org/10.17660/ActaHortic. 2004.638.43
- Bhatt R, Singh J, Laing AM, Meena RS, Alsanie WF, Gaber A, Hossain A (2021) Potassium and water deficient conditions influence the growth, yield and quality of ratoon sugarcane (*Saccharum* officinarum L.) in a semi-arid agroecosystem. Agron 11:2257. https://doi.org/10.3390/agronomy11112257
- Bokhtiar SM, Paul GC, Alam KM (2008) Effects of organic and inorganic fertilizer on growth, yield, and juice quality and residual effects on ratoon crops of sugarcane. J Plant Nutr 31:1832–1843. https://doi.org/10.1080/01904160802325545
- Brunetti G, Traversa A, De Mastro F, Cocozza C (2019) Short term effects of synergistic inorganic and organic fertilization on soil properties and yield and quality of plum tomato. Sci Hortic 252:342–347. https://doi.org/10.1016/j.scienta.2019.04.002
- Buráňová Š, Černý J, Mitura K, Lipińska KJ, Kovářík J, Balík J (2014) Effect of organic and mineral fertilizers on yield parameters and quality of wheat grain. Sci Agric Bohem 47:2. https://doi.org/ 10.1515/sab-2016-0008
- Cai ZC, Qin SW (2006) Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Huai-Hai Plain of China. Geoderma 136:708–715. https://doi.org/10. 1016/j.geoderma.2006.05.008
- Cao G et al (2018) Balanced fertilization for the influence of desert crested pear growth and quality. J Appl Ecol 29:2477–2484
- Cao S, Zhang P, Li JK, Wang H, He GH, Luo DL (2019) Effect of different preservatives on the storage quality of red peach. Pack Engin 40:14-19. https://doi.org/10.19554/j.cnki.1001-3563.2019. 17.003
- Chang MH, Shi ZJ, Wu WR (2006) Formula fertilization on greenhouse peach apricot fruit vegetative growth and fruit quality. Gardening, North Core (02) Peking Uni 2:60-61.
- Chater JM, Garner LC (2018) Foliar nutrient applications to "Wonderful" pomegranate (*Punica granatum* L.). I. Effects on fruit mineral nutrient concentrations and internal quality. Sci Hortic 244:421–427. https://doi.org/10.1016/j.scienta.2018.04.022
- Chauhan N, Sankhyan NK, Sharma RP, Singh J, Gourav (2020) Effect of long-term application of inorganic fertilizers, farm yard manure and lime on wheat (*Triticum aestivum* L.) productivity, quality and nutrient content in an acid Alfisol. J Plant Nutr 14:1–10. https://doi.org/10.1080/01904167.2020.1783298
- Chen D, Tu MY, Li J, Sun SX, Song HY, Liu CY, Jiang GL (2020) Effects of 'gather soil ridging + narrow strains with broad- rows on growth, yield and quality of peach. J Southwest Agric Uni 33:40-45. https://doi.org/10.16213/j.cnki.scjas.2020.1.007
- Chen J, Zhao QC, Liao H, Fan SS, Chen SX, Du XY, He WM, Chen XH (2020) Effects of different nitrogen fertilizer rates on yield and economic benefits of cucumber under drip irrigation. Vegetables 10:19–22

- Chen NX, Li YL, Yang XG, Wang YC, Huang ZH (2018) Commodity organic fertilizer instead of chemical fertilizer effect on watermelon production. Shanghai Veg 163(06):55–57
- Chen XQ, Cao WZ, Zuo J, Li GL, Shi SG, Zhao HY (2020) Different N application rate on grain yield and quality of south japonica rice 46. Mod Agric Sci Technol 760(02):17–23
- Chen Y, Li SY, Zhu A, Liu K, Zhang YJ, Zhang H, Gu JF, Zhang WY, Liu LJ, Yang JC (2022) Rate and earing fertilizer N application rate of high-quality eating live on rice yield and quality. J Crops 48(03):656–666
- Chen YF, Zhou H, Song LB, Fan C, Wang YF (2021) Effects of organic fertilizer and microbial agents on yield and quality of Xinning navel orange. Bull Chinese Agron 37:38–42
- Chen YM, Zhao H, Xiao HJ, Xie TT, Qin S, Hu L (2021) Reduction of nitrogen with organic material for corn-cabbage crop yield crop rotation system, the influence of the photosynthetic characteristics and product quality. J App Ecol 32:4391-4440. https://doi.org/10.13287/j.1001-9332.202112.015
- Chen Z, Ding W, Luo Y et al (2014) Nitrous oxide emissions from cultivated black soil: a case study in Northeast China and global estimates using empirical model. Global Biogeochem Cycles 28:1311–1326. https://doi.org/10.1002/2014GB004871
- Chen ZC, Yan MJ, Lin Q, Li J, Zhang MQ (2005) Balanced fertilization effect on yield and quality pomelo. Fujian Fruit Trees 1:10–12
- Choudhary K, Sharma SR, Jat R, Didal VK (2017) Effect of organic manures and mineral nutrients on quality parameters and economics of sesame (*Sesamum indicum* L.). J Pharmacogn Phytochem 6:263-265. E-ISSN: 2278-4136
- Citak S, Sonmez S (2010) Effects of conventional and organic fertilization on spinach (*Spinacea oleracea* L.) growth, yield, vitamin C and nitrate concentration during two successive seasons. Sci Hortic 126:415–420. https://doi.org/10.1016/j.scienta.2010.08.010
- Çolpan E, Zengin M, Özbahçe A (2013) The effects of potassium on the yield and fruit quality components of stick tomato. Hortic Environ Biotechnol 54:20–28. https://doi.org/10.1007/ s13580-013-0080-4
- Conry MJ (1984) Effects of sowing date and autumn nitrogen on winter barley: 2. grain quality. Ir J Agric Res 23: 217-222. https://www. jstor.org/stable/25556093
- Çürük S, Sermenli T, Mavi K, Evrendilek F (2004) Yield and fruit quality of watermelon (*Citrullus lanatus* (Thumb.) Matsum. & Nakai.) and melon (*Cucumis melo* L.) under protected organic and conventional farming systems in a Mediterranean region of Turkey. Biol Agric Hortic 22:173–183. https://doi.org/10.1080/ 01448765.2004.9754999
- Das A, Layek J, Babu S et al (2020) Influence of land configuration and organic sources of nutrient supply on productivity and quality of ginger (*Zingiber officinale* Rosc.) grown in Eastern Himalayas. India. Environ Sustain 3:59–67. https://doi.org/10.1007/ s42398-020-00098-x
- Dasa A, Patel DP, Kumar M, Ramkrushna GI, Mukherjee A, Layek J, Ngachan SV, Buragohain J (2017) Impact of seven years of organic farming on soil and produce quality and crop yields in eastern Himalayas, India. Agric Ecosyst Environ 236:142–153. https://doi.org/10.1016/j.agee.2016.09.007
- De Oliveira AB, de Almeida Lopes MM, Moura CFH et al (2017) Effects of organic vs. conventional farming systems on quality and antioxidant metabolism of passion fruit during maturation. Sci Hortic 222:84–89. https://doi.org/10.1016/j.scienta.2017.05.021
- Deng LC, Xiu CH, Fan LY (2012) Effects of different ratios of nitrogen, phosphorus and potassium fertilizer and organic fertilizer on the growth, yield and quality of rape. Soil Fert Sci China 5:31–34
- Deng LC, Xue CH, Fan LY (2012) NPK fertilizer and organic fertilizer ratio of different effects on rape growth and yield and quality. Soil Fert China 5:31–34



- Deng XF, Lv CH, Huang LQ, Zhang HQ, Zhao ZQ, Liu XW (2018) Effects of spraying selenium in different forms and at different stages on selenium absorption and accumulation and main quality indexes of 'Jin-tao' kiwifruit. J Fruit Sci 35:1385-1392. https://doi.org/10.13925/j.cnki.gsxb.20180110
- Ding W (2006) Zhangzhou pomelo application research of city sludge compost. J Safety Environ 5:56–59
- Ding W (2013) Effect of controlled release fertilizer oil the yield and quality of banana and nutrient use efficiency. Fujian J Agric Sci 28(01):47-50. https://doi.org/10.19303/j.issn.1008-0384.2013. 01.012
- Dong YB, Peng YS, Li KY, Tian SJ, Xu RH, Wu CX, Ren MJ (2021) Effects of planting density and fertilization amount on net photosynthetic rate, yield and quality of glutinous sorghum for wine. Anhui Agric Sci 49(07):20–24
- Du B, Xie TZ, Hu XQ, Zhang SJ, Zhang WX (2020) Organic nitrogen fertilizer on rice plant growth and the influence of yield and quality. J Agron 10(09):1–6
- Du CY, Zhang Q, Feng T, Zhu ZJ, Tong YA (2020) Effects of organic and chemical fertilizers on yield, quality and leaf nutrient of cherry. Agric Res Arid Reg 38:105–109
- Du QJ, Yang YY, Zhang JX, Li JQ, Xiao HJ, Wang JQ (2021) Microporous membrane irrigated with water fertilizer consumption on cucumber photosynthesis parameters, the influence of nutrient characteristics, quality and yield. J China Agric Uni 26:45–46
- Du Y (2008) Effects of different sowing amounts and fertilization levels on autumn buckwheat yield in Meigu County. Mod Agric Sci Technol 494(24):171–172
- Du YX, Li J, Gao JY, Liu HM, Peng MX, Li JX, Yue JQ (2017) Effect of organic and inorganic combined application on yield and quality of lemon. Chinese Agric Sci Bull 33(07):92–97
- Du ZH, Fan HK, Lv ZF, Wu DY (2011) Effects of different fertilization schemes on the growth, yield and quality of Fuji apples in Weibei Dryland. Northwest Agric J 20:121–125
- Duan Y, Xu M, Gao S, Yang X, Huang S, Liu H, Wang B (2014) Nitrogen use efficiency in a wheat-corn cropping system from 15 years of manure and fertilizer applications. Field Crops Res 157:4–56. https://doi.org/10.1016/j.fcr.2013.12.012
- Duarte AP, Mason SC, Jackson DS, J, de C Kiehl (2005) Grain quality of Brazilian maize genotypes as influenced by nitrogen level. Crop Sci 45:1958. https://doi.org/10.2135/cropsci2004.0587
- Efthimiadou A, Bilalis D, Karkanis A, Williams BF, Eleftherochorinos I (2009) Effects of cultural system (organic and conventional) on growth, photosynthesis and yield components of sweet corn (*Zea mays* L.) under semi-arid environment. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. https://doi.org/10.15835/nbha3 723201
- El-Kassas SE (1984) Effect of iron nutrition on the growth, yield, fruit quality, and leaf composition of seeded Balady lime tress grown on sandy calcareous soils. J Plant Nutr 7:301–311. https://doi. org/10.1080/01904168409363197
- Ennab HA (2016) Effect of organic manures, biofertilizers and NPK on vegetative growth, yield, fruit quality and soil fertility of eureka lemon trees (*Citrus limon* (L.) Burm). J Soil Sci Agric Eng 7:767-774. https://doi.org/10.21608/jssae.2016.40472
- Erhart E, Hartl W, Putz B (2005) Biowaste compost affects yield, nitrogen supply during the vegetation period and crop quality of agricultural crops. Eur J Agron 23:305–314. https://doi.org/10. 1016/j.eja.2005.01.002
- Fallahi E, Fallahi B, Neilsen GH, Neilsen D, Peryea FJ (2010) Effects of mineral nutrition on fruit quality and nutritional disorders in apples. Acta Hortic 868:49-60. https://doi.org/10.17660/ActaH ortic.2010.868.3
- Fan FR (1984) Potash fertilizer on tomato yield, quality and disease resistance early correlation studies. Soil Fert 1:38–39

- Fan WG, Yang SA, Liu GQ, An HM, Xiang QY, Wu XG, Wu AG (2006) Effects of different fertilization levels on yield, quality and economic benefits of navel orange. J Mtn Agric Biol 3:194–196
- Feng HD, Chen HY, Dang ZH G, Ni B, He CC, Wei ZY, Chen YY (2020) Soil properties, leaf nutrients and fruit quality response to substituting chemical fertilizer with organic manure in a mango orchard. Appl Ecol Environ Res 18:4025-4033. https://doi.org/ 10.15666/aeer/1803\_40254033
- Feng HD, Dang ZG, Ni B, Chen HY, He CC, Wei ZY, Chen YY (2019) Sheep droppings fermentation fertilizer instead of chemical fertilizer for mangos, leaf nutrient soil characteristics and the influence of the fruit quality. Soil Fert China 6:190–195
- Feng TT, Huang HC, Chen F, Fan JD, Wei M (2018) Effects of different earthworm manure application rates on agronomic characters yield and quality of continuous cropping cucumber. J Southern Agric 49:1575–1580
- Gai X, Liu H, Zhai L, Tan G, Liu J, Ren T, Wang H (2016) Vegetable yields and soil biochemical properties as influenced by fertilization in Southern China. Appl Soil Ecol 107:170–181. https://doi. org/10.1016/j.apsoil.2016.06.001
- Gan GX, Tang QC, Zhao JF (1996) Effects of manganese fertilizer on yield and quality of rape. Seed 6:24-25. https://doi.org/10. 16590/j.cnki.1001-4705.1996.06.033
- Gao C, El-Sawah AM, Ali DFI, Hamoud YA, Shaghaleh H, Sheteiwy MS (2020) The integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (Zea mays L.). Agron 10:319. https://doi.org/10.3390/ agronomy10030319
- Gao DJ, Cao CL (1997) Study on the fertilization of sorghum early maturing hybrid combination Black Dragon 11Ax seven resistance seven. Shanxi Agric Sci 4:48–51
- Gao JJ, Yu XY (1998) Effects of zinc application on growth, yield and quality of rape. Northern Hortic 5:20–21
- Gao L, Yu XB, Li R, Yang QQ, Cui XB, Li SY, Wang P (2017) The effect of biogas slurry formula fertilizer on banana yield, quality and banana orchard effects of soil quality. J Trop Biol 8(02):209-215. https://doi.org/10.15886/j.cnki.rdswxb.2017.02.014
- Gao X, Wang JJ, Li X, Tong YN, Ma HY, Yang XL, Zhang SX, Liang MZ, Lu S (2021) Application of soil conditioner eggplant yield and soil nutrient content of research. Tianjin Agric Sci 27:87–90
- Geng JB, Zhang C, Li Q, Hu HY, Tian R, Ma XL (2018) Sulphur on small rape yield, quality and the influence of physical characteristics. Soil Fert China 4:121–125
- Geng JB, Zhang C, Li Q, Hu HY, Tian W, Ma XL (2017) Effects of sulfur fertilizer on yield, quality and physiological characteristics of *Brassica napus*. Soil Fert Sci China 4:121–125
- Gezahegn AM, Halim RA, Yusoff MM, Wahid SA (2017) Effect of incorporation of crop residue and inorganic fertilizer on yield and grain quality of maize. Indian J Agric Res 51:574-579. https:// doi.org/10.18805/IJARe.A-264
- Gonzalez D, Almendros P, Obrador A, Alvarez JM (2019) Zinc application in conjunction with urea as a fertilization strategy for improving both nitrogen use efficiency and the zinc biofortification of barley. J Sci Food Agric 99:4445–4451. https://doi.org/ 10.1002/jsfa.9681
- Gopinath KA, Saha S, Mina BL, Pande H (2008) Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. Nutr Cycl Agroecosyst 82:51–60. https://doi.org/10.1007/ s10705-008-9168-0
- Gopinath KA, Saha S, Mina BL, Pande H, Srivastva AK, Gupta HS (2009) Bell pepper yield and soil properties during conversion from conventional to organic production in Indian Himalayas. Sci Hortic 3:339–345. https://doi.org/10.1016/j.scienta.2009.05.016



- Gregory MP, Preston KA, John PR, John KF (2006) Apple orchard productivity and fruit quality under organic, conventional, and integrated management. Agric Ecosyst Environ 41:99-107. https:// doi.org/10.21273/HORTSCI.41.1.99
- Gu DY, Jiao J, Liu ZL, Yan WQ, Gao JJ (2019) Reduction of fertilizer and organic fertilizer effect on big watermelon growth and quality of tunnel in early spring. North Garden 23:48–56
- Guan TX, Ma GT, Ma ZL, Liu ZF, Zhang FQ, Zhang YF, Deng JX, Ma XH, Han YS (2021) Continuous use of chicken manure on outdoor cucumber yield, quality and the influence of soil properties. J Plant Nutr Fert 27:1351–1360
- Guo B (2022) Nitrogen fertilizer effect on hot pepper production, nutrient and quality. Anhui Agric Sci 50:158–159
- Guo JY, Jiang Q, Zhao JB, Ren F, Li XY, Wang Z, Wang, SD, Zhang Y (2020) Application of bag controlled-release fertilizer in hillside peach orchard of Beijing. China Fruits 2:23-25. https://doi.org/ 10.16626/j.cnki.issn1000-8047.2020.02.005
- Guo XZ, Huang PH, Lin SS, Liu DF, Chen W, Xu WR, Wei ZH (2016) Organic fertilizer to red meat because the influence of fruit quality and yield. Agric Sci Technol Comm 9:152–154
- Guo YF, Zhang ZX, Luan FS (1999) The effect of potassium chloride and potassium sulfate on vegetable production quality. Northern Hortic 1:2
- Guo YJ, Yin YL, Zhang J, Han L, Guo YJ, Tang H (2011) Effects of fertilization on yield and nutrient mass fraction of stem and leaf in sweet sorghum. J Southwest Uni Studies 33(10):21-26. https:// doi.org/10.13718/j.cnki.xdzk.2011.10.024
- Hakan E, Mehmet Z (2016) Response of maize for grain to potassium and magnesium fertilizers in soils with high lime contents. J Plant Nutr 40:93–103. https://doi.org/10.1080/01904167.2016. 1201493
- Han ML, Zhou TG (2021) Livestock and poultry dung and mushroom residue organic fertilizer effect on cabbage and cucumbers. Zhejiang Agric Sci 62:2442-2444. https://doi.org/10.16178/j.issn. 0528-9017.20203569
- Hasani M, Zamani Z, Savaghebi G, Sofla HS (2015) Effect of foliar and soil application of urea on leaf nutrients concentrations, yield and fruit quality of pomegranate. J Plant Nutr 39:749–755. https:// doi.org/10.1080/01904167.2015.1047525
- Hashim AF, Hatim AAA, Somaya SM (2016) Effects of chemical and bio-fertilizers on yield, yield components and grain quality of maize (*Zea mays L.*). Afr J Agric Res 45:4654–4660. https://doi. org/10.5897/AJAR2016.11619
- Haynes RJ, Goh KM (1987) Effects of nitrogen and potassium applications on strawberry growth, yield and quality. Commun Soil Sci Plant Anal 18:457–471. https://doi.org/10.1080/0010362870 9367833
- Hazarika TK, Aheibam B (2019) Soil nutrient status, yield and quality of lemon (*Citrus limon* Burm.) cv. "Assam lemon" as influenced by bio-fertilizers, organics and inorganic fertilizers. J Plant Nutr 42:1–11. https://doi.org/10.1080/01904167.2019.1584213
- He JX, Zhao JC, Bai WB, Zheng L, Zhang YC, Yu MM, Kimoto H, Saito M, Lu GH (2019) The effect of foliar oligosaccharide spraying on the growth and quality of lettuce. Agrometeorol China 40(12):783–792
- He L, Liu XX, Yu TH, Hou X, Sun MM, Ge SF, Jiang YM (2018) Effects of applying water-soluble fulvic acid fertilizer during fruit-swelling period on apple leaf growth, fruit quality and yield. Shandong Agric Sci 50:79-83. https://doi.org/10.14083/j. issn.1001-4942.2018.04.017
- He LZ, Ding XT, Jin HJ, Zhang HM, Cui JW, Zhou Q, Yu JZ (2021) Cotton goods rock and coconut chaff on cucumber growth, photosynthesis, yield and quality. Chinese Veg 10:91-96. https://doi. org/10.19928/j.cnki.1000-6346.2021.1045

- He XT, Niu JY, Liu JH (2010) The influence of different fertilization levels on grain yield and quality of apple. J Gansu Agric Uni 45(02):83-86. https://doi.org/10.13432/j.cnki.jgsau.2010.02.023
- He YQ, Xiong LM, Fan BN, Long SZ, He TG (2012) Influence of 25% organic bio-organic compound-mixed fertilizer on the yield and quality of banana. J Southern Agric 43(01):67–69
- Herencia JF, Ruiz-Porras JC, Melero S, Garcia-Galavis PA, Morillo E, Maqueda C (2007) Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations, and yield. Agron J 99:973. https://doi.org/10.2134/agron j2006.0168
- Hlisnikovský L, Menšík L, Kunzová E (2020) The development of winter wheat yield and quality under different fertilizer regimes and soil-climatic conditions in the Czech Republic. Agron 10:1160. https://doi.org/10.3390/agronomy10081160
- Hmad K, Jan MT, Marwat KB, Arif M (2009) Organic and inorganic nitrogen treatments effects on plant and yield attributes of maize in a different tillage systems. Pak J Bot 4:99–108
- Hou D, Kuai JL, Yue HZ, Li YL, Zhang DQ, Yao T (2021) Replacing part of the fertilizer use functional mixed microbial agents affect greenhouse pepper growth and quality. Zhejiang Agric Sci 62:1736-1739. https://doi.org/10.16178/j.issn.0528-9017.20210 919
- Hou HJ, Han J, Huang JT, Luo XA, Wan YJ, Qin HL (2020). Effects of combined application of organic fertilizer and rice straw on the yield and quality of ponkan citrus in Northwest Hunan. Hunan Agric Sci 417(06):38-41. https://doi.org/10.16498/j.cnki.hnnykx. 2020.006.010
- Hu CX, Deng BE, Liu TC (1996) The influence of nitrogen levels on vegetable quality. Soil Fert 3:34–36
- Hu JJ (2018) Research on the effects of ecological organic fertilizer on lettuce quality. Jilin Agric 5:86-87. https://doi.org/10.14025/j. cnki.jlny.2018.05.028
- Hu SY, Zhu RW (1999) New organic fertilizer on chili, tomato yield, quality and the influence of enzyme activity. J Huazhong Agric Uni 2:4
- Hu Y, Cong S, Zhang H (2021) Comparison of the grain quality and starch physicochemical properties between japonica rice cultivars with different contents of amylose, as affected by nitrogen fertilization. Agric 11:616. https://doi.org/10.3390/agricultur e11070616
- Huang DF, Huang HS, Huang GH (2010) "High lida" "plant growth biological photosynase trace element leaf fertilizer on the yield effect of pomelo test preliminary report. Fruit Growers Friend 7:6
- Huang L, Yang J, Gao W, Yang W, Cui X, Zhuang H (2016) Effects of pig slurry as basal and panicle fertilizer on trace element content and grain quality in direct-seeding rice. Sustain 8:714. https:// doi.org/10.3390/su8080714
- Huang M, Liang T, Wang L (2015) Nitrous oxide emissions in a winter wheat - summer maize double cropping system under different tillage and fertilizer management. Soil Use Manag 31:98–105. https://doi.org/10.1111/sum.12170
- Huang PM, Zhang YJ, Mo GG, Xie RL, Liu JY, Mou HF, Tian QL, Huang WH, Wu YY (2021) Effects of the application of fertilizer of magnesium, boron and zinc on banana growth, fruit yield and quality. J Guangxi Agric 36:46–54
- Huang T (2011) Organic fertilizer for upland crops yield, quality and nutrient loss impact study. Hunan Agric Uni.
- Hussain S, Maqsood M, Ijaz M, Ul-Allah S, Sattar A, Sher A, Nawaz A (2020) Combined application of potassium and zinc improves water relations, stay green, irrigation water use efficiency, and grain quality of maize under drought stress. J Plant Nutr 43:2214–2225. https://doi.org/10.1080/01904167.2020.1765181
- Jalilian J, Ali S, Modarres-Sanavy M, Saberali SF, Sadat-Asilan K (2012) Effects of the combination of beneficial microbes and



nitrogen on sunflower seed yields and seed quality traits under different irrigation regimes. Field Crops Res 127:26–34. https://doi.org/10.1016/j.fcr.2011.11.001

- Järvan M, Edesi L (2009) The effect of cultivation methods on the yield and biological quality of potato. Agron Res 7:289–299
- Javeed HMR, Qamar R, Rehman A, Ali M, Rehman A, Farooq M, Zamir SI, Nadeem M, Cheema MA, Shehzad M, Zakir A, Sarwar MA, Iqbal A, Hussain M (2019) Improvement in soil characteristics of sandy loam soil and grain quality of spring maize by using phosphorus solubilizing bacteria. Sustain 11:7049. https://doi.org/10.3390/su11247049
- Jiang CJ, Wang N, Wang XG, Wu D, Zhao KN, Dang XS, Qu SN (2017) Effect of Ca, Mo and B fertilizer combined application on growth development, yield and kernel quality of peanut. Chinese J Oil Crop Sci 39(04):524–531
- Jiang JH, Shen QY, Lou L, Jin BS, Wang Z, Shen JG, Jiang JZ (2021) Effects of different water-soluble fertilizers on yield and quality of pitaya cultivated in greenhouse. Zhejiang Agric Sci 62(11):2203-2206. https://doi.org/10.16178/j.issn.0528-9017. 20210900
- Jiang SR, Mao LZ, Zhao K, Zhu HS (2021) Effects of amino acids and humic acid fertilizer on growth and nutritional quality of soilless cultivated lettuce. Vegetable 7:28–31
- Jifon JL, Lester GE (2009) Foliar potassium fertilization improves fruit quality of field-grown muskmelon on calcareous soils in south Texas. J Sci Food Agric 89:2452–2460. https://doi.org/ 10.1002/jsfa.3745
- Jing CQ, Luo ZH, Guo MP (2020) Effects of different fertilization treatments on economic traits and yield of buckwheat. Mod Agric Sci Technol 763(05):21–25
- Jing YP, Li Y, Bo LJ, Zhang YP, Wang YQ, Fu LY, Zhong ZW (2019) Organic fertilizer partly replace fertilizer on crop yield and soil nitrogen migration. Shandong Agric Sci 51(07):48-54. https://doi.org/10.14083/j.issn.1001-4942.2019.07.012
- Kadam SS, Kachhave KG, Chavan JK, Salunkhe DK (1977) Effect of nitrogen, rhizobium inoculation and simazine on yield and quality of Bengal gram (*Cicer arietinum* L.). Plant Soil 47:279–281. https://doi.org/10.1007/BF00010392
- Kakar K, Nitta Y, Asagi N, Komatsuzaki M, Shiotsu F, Kokubo T, Xuan TD (2019) Morphological analysis on comparison of organic and chemical fertilizers on grain quality of rice at different planting densities. Plant Prod Sci 22:510–518. https:// doi.org/10.1080/1343943X.2019.1657777
- Kakar K, Xuan TD, Noori Z, Aryan S, Gulab G (2020) Effects of organic and inorganic fertilizer application on growth, yield, and grain quality of rice. Agric 10:544. https://doi.org/10. 3390/agriculture10110544
- Kalinova J, Vrchotova N (2011) The influence of organic and conventional crop management, variety and year on the yield and flavonoid level in common buckwheat groats. Food Chem 127:602–608. https://doi.org/10.1016/j.foodchem.2011.01.050
- Karma D, Kang YC (1993) Effects of nitrogen fertilizer on green tree yield. Soil Fert 6:18–20
- Kaur A, Kaur N, Singh H, Murria S, Jawanda SK (2021) Efficacy of plant growth regulators and mineral nutrients on fruit drop and quality attributes of plum cv. Satluj purple. Plant Physiol Rep 26:541–547. https://doi.org/10.1007/s40502-021-00609-w
- Khaim S, Chowdhury MAH, Saha BK (2014) Organic and inorganic fertilization on the yield and quality of soybean. J Bangladesh Agric Univ 11:23–28. https://doi.org/10.3329/jbau.v11i1. 18199
- Khan MZ, Akhtar ME, M, ul Hassan, Mahmood MM, MN, Safdar (2012) Potato tuber yield and quality as affected by rates and sources of potassium fertilizer. J Plant Nutr 35:664–677. https:// doi.org/10.1080/01904167.2012.653072

- Kiraci S (2018) Effects of seaweed and different farm manures on growth and yield of organic carrots. J Plant Nutr 41:716–721. https://doi.org/10.1080/01904167.2018.1425435
- Kong LG, Wang YH, Han XD, Bo HJ, Sun J, Wang LJ (2018) Grain spring foliar fertilizer on rice growth under different nitrogen levels and the influence of rice quality. Jiangsu Agric Ind Learn 34(04):790–798
- Kong XZ (2019) Nitrogen management of wheat-corn anniversary of crop growth and yield, the influence of the quality. Northwest Agric Forestry Uni Sci Technol.
- Kumar M, Ray PK (2018) Yield and fruit quality of litchi (*Litchi chinensis* Sonn.) under the influence of organic and inorganic nutrient management practices. Acta Hortic 1211:53-64. https://doi.org/ 10.17660/ActaHortic.2018.1211.8
- Kuscu H, Turhan A, Ozmen N, Aydinol P, Demir AO (2014) Optimizing levels of water and nitrogen applied through drip irrigation for yield, quality, and water productivity of processing tomato (*Lycopersicon esculentum* Mill.). Hortic Environ Biotechnol 55:103–114. https://doi.org/10.1007/s13580-014-0180-9
- Labbilta T, Ait-El-Mokhtar M, Abouliatim Y, Khouloud M, Meddich A, Mesnaoui M (2021) Innovative formulations of phosphate glasses as controlled-release fertilizers to improve tomato crop growth, yield and fruit quality. Molecules 26:3928. https://doi. org/10.3390/molecules26133928
- Ladislav H, Lukas H, Eva K (2018) The effect of mineral fertilizers and farmyard manure on winter wheat grain yield and grain quality. Plant Soil Environ 64:491-497. https://doi.org/10.17221/342/ 2018-PSE
- Lai YH, Yin LX (2011) Soil testing formula fertilization effect on yield and quality pomelo. Fujian Fruit Trees 1:33–34
- Lao TY (1993) The study of "multi-effect good" on improving the yield and quality of high-quality rice. J Guangxi Agric Uni 2:27–32
- Lazcano C, Revilla P, Malvar RA, Domínguez J (2011) Yield and fruit quality of four sweet corn hybrids (*Zea mays*) under conventional and integrated fertilization with vermicompost. J Sci Food Agric 91:1244–1253. https://doi.org/10.1002/jsfa.4306
- Lee J, Son D, Hwang S, Min B et al (2018) Effect of year, location, compost, and mixed oilseed cake on bulb and scale characteristic, nutrients and organic compounds in bulb and leaf, and storage quality in organic bulb onion. J Plant Nutr 41:1636–1651. https:// doi.org/10.1080/01904167.2018.1458867
- Lei T, Xu E, Tang J, Song NJ, Peng LZ (1992) Effects of gibberellin plus cytokine coating and girdling on nutritional physiology of navel orange. Chinese Citrus 4:22–23
- Li CM, Pei XY, Zhang HY, Gao TM, Li F, Wang L, Wei SL (2021) Effects of different nitrogen supply levels on nitrogen metabolism, yield and quality of xiazhi hemp. J Henan Agric Sci 50:63-70. https://doi.org/10.15933/j.cnki.1004-3268.2021.09.008
- Li CM, Pei XY, Zhang HY, Gao TM, Li F, Wang L, Wei SL (2021) For different nitrogen levels of summer sesame, yield and nitrogen metabolism and influence on the quality. Henan Agric Sci 50:63-70. https://doi.org/10.15933/j.cnki.1004-3268.2021.09.008
- Li CP, Wang SP, Du L, Hong J, Huang X, Zhang GY, Zhang LH, Ye LX, Lian ZC, Jiang L, Chen G (2020) Effects of different potassium application methods on yield, quality and soil condition of lettuce. Hubei Agric Sci 59(07):28-33. https://doi.org/10.14088/j. cnki.issn0439-8114.2020.07.006
- Li CY, Xiong B, Zhang L, Jiang B, Gao J, Li ZG, Wang QJ (2016) Taoyuan debris is crushing returning to improve soil physical and chemical properties improve the quality of the peach. J Agric Engin 32:161–167
- Li DL, Wang YB, Ye HB, Guo ZG (2021) Effect of balanced nutrient fertilizer of citrus on quality of Huangyan Satsuma. Fert Health 48:36–41



- Li F, Yuan C, Lao D et al (2020) Drip irrigation with organic fertilizer application improved soil quality and fruit yield. Agron J 112:608–623. https://doi.org/10.1002/agj2.20052
- Li FL, Zhang Q, Wang HP, An MY, Luo T (2018) Effects of soil amendments on yield, quality of honey pomelo and soil properties. Chinese Agric Sci Bull 34:39–44
- Li GD, Liu JX, Shi Y, Wang XJ, Hou LP, Zhang Y (2021) Effects of exogenous silicon on growth, photosynthetic and quality characteristics of lettuce. Northern Hortic 16:49–55
- Li H, Liu H, Gong X, Li S, Pang J, Chen Z, Sun J (2020) Optimizing irrigation and nitrogen management strategy to trade off yield, crop water productivity, nitrogen use efficiency and fruit quality of greenhouse grown tomato. Agric Water Manag 28:106570. https://doi.org/10.1016/j.agwat.2020.106570
- Li HY, Zhou XS, Yang XT, Liu MH, Zhao HC, Zheng GP, Chen LQ, He C (2019) Cold reduction of nitrogen fertilization on rice production quality and the influence of the lodging resistance. J Heilongjiang August First Land Reclam Uni 31(05):1–8
- Li JQ (2002) Effects of balanced fertilization on yield and quality of navel orange. J Guizhou Uni 3:182–185
- Li LN, Zhan DJ, Peng TS, Hao XL (2021) Effect of humic acid fertilizer on the yield and quality of cucumber. Agric Technol 41:92-94. https://doi.org/10.19754/j.nyyjs.20210815024
- Li NJ (2021) The effects of slow-release fertilizer on cucumber growth. Chinese Fruit 41:61-63. https://doi.org/10.19590/j.cnki.1008-1038.2021.03.012
- Li PF, Tan H, Wang JH, Yang PL (2017) Effect of water and fertilizer conditions under drip irrigation on yield, quality of cherry and physicochemical properties of soil. Trans Chinese Soc Agric Mach 48:236–246
- Li TT, Zhai BN, Li YG, Liu LL, Yan MH, Zhao ZY (2013) Organic and inorganic fertilizer on dry land "fuji" apple quality. Soil Fert 300(21):178–181
- Li W, Huang JX, Su M, Peng SH, Ou YL, Zhou W (2021) Effects of several high potassium compound fertilizers on pitaya fruit. Agric Technol Newsletter 12:209–212
- Li WY, Tian HY, Yin ZR (1972) Effects of soil fertility and fertilization on the fertility of maize sorghum and its cultivation measures for early maturation and abundant yield. Mech Farming Inst Jilin Acad Agric Sci 3:43-49. https://doi.org/10.16423/j.cnki.1003-8701.1979.03.007
- Li Y, Luo SG, Liu YY, Cheng Y, Zhao JM, Jiang BW (1999) Selenium on tomato leaf in glutathione peroxidase activity and the influence of yield and quality. Shandong Agric Sci 6:38–39
- Li Y, Sun Y, Liao et al (2017) Effects of two slow-release nitrogen fertilizers and irrigation on yield, quality, and water-fertilizer productivity of greenhouse tomato. Agric Water Manag 186:139–146. https://doi.org/10.1016/j.agwat.2017.02.006
- Li Y, Wang F, Li QH, He CM, Li XJ (2007) Minnan dryland soil potassium magnesium fertilizer applied study of sweet pomelos, banana effect. Phosphate Fert Comp Fert 4:68–69
- Li YE, Liu FX, Xie TY, Luo GH, Lei T (2008) Effects of fertilizer application on yield and fruit quality of Initial bearing tree of HangWan sweet pomelo. Fujian Fruit Trees 2:24–26
- Li YJ, Yi SL, Gao HJ, Zhu XT, Qin Y, Jing GQ (2019) Effects of different organic fertilizers on growth, nutrient uptake and product quality of a debilitated tree from a highly cultivated species of Wenzhou honey Mandarin. Acta Agric Zhejiangensis 31(11):1871–1879
- Li YO, Jia XH, Chen Q (2008) Different fertilizer measures impact on yield and quality of organic peach. North Garden 11:46–48
- Li ZZ (2015) Study on the fertilizer efficiency of Honey pomelo with Kim Jong Da nitro-compound fertilizer. Mod Agric Sci Technol 11:103

- Li, SX(2020) Effects of organic fertilizer substitution of some chemical fertilizers on the nutrition and fruit quality of grapefruit trees. Fujian Agric For Uni 3:1-5. https://doi.org/10.27018/d.cnki.gfjnu.2019.000041
- Lian H, Ma GS, Li M, Zhang F, Zhang JM (2021) Spines spore trichoderma agent on cucumber physiological characteristics and the influence of yield and quality. J China Agric Uni 26:42–52
- Liang B, Zhao W, Yang X, Zhou J (2013) Fate of nitrogen-15 as influenced by soil and nutrient management history in a 19-year wheat-maize experiment. Field Crops Res 144:126–134. https:// doi.org/10.1016/j.fcr.2012.12.007
- Liang F, Nong DL, Wu HX, Li GZ (2021) Effects of Camellia oleifera shell organic fertilizer as base fertilizer on soil characteristics and quality of citrus orchard. Agric Technol 41(07):21-23. https://doi. org/10.19754/j.nyyjs.20210415006
- Liang RB (1986) Effects of different fertilization on the regenerative properties of Nui perennial ryegrass. Guizhou Anim Husb Veterinary Sci Technol 2:44–47
- Liang XP, Fan CH, Xu XL, Liu JB, Li XN, Hu SB, He ST (2017) Effects of water and fertilizer coupling on fruit yield, quality and leaf photosynthetic performance of "Chongyang Hong" peach. Northern Hortic 23:52–57
- Liao CQ, Xiong JY, Yang SP, Wei ZK (2019) Study on application effect of different application amount of biogas fertilizer on navel orange. Mod Agric Sci Technol 9:53
- Liao HX (2013) Effects of applying bio organic fertilizer on yield, quality and soil fertility of navel orange. Fujian Agric Sci Technol 7:75-77. https://doi.org/10.13651/j.cnki.fjnykj.2013.07.039
- Liao Q, Jiang ZP, Xing Y, Xiong LM, Chen GF, Yang SE, Tan YM (2015) Two sugarcane varieties with different fertilizer treatment on the growth, yield and soil properties. J Southern Agric 46(09):1596–1601
- Lin C, Li QH, He CM, Wang F, Li Y (2008) Effect of new potassium magnesium sulfate fertilizer on yield, quality and benefit of Guanxi pomelo. Fujian Agric Sci Technol 3:64–65
- Lin JX (2015) The application effects of biological organic fertilizer on pomelo analysis. Explor Agric Taiwan 3:61-63. https://doi. org/10.16006/j.cnki.twnt.2015.03.014
- Lin XL (2019) Effects of different potassium fertilizer application rates on yield and quality of navel orange. Fujian Agric Sci Technol 4:26-28 https://doi.org/10.13651/j.cnki.fjnykj.2019.04.008
- Ling XP (2018) Coupling of water and fertilizer on soil environment and fruit in peach orchard Influence of yield and quality. Northwest A&F Uni.
- Liu CY, Zhou L, Chen DL, Chen YA (2021) Effects of bacterial manure on soil fertility and above-ground parts of *Prunus Persica* (L.). J Henan Agric Uni 54:597-603. https://doi.org/10.16445/j.cnki. 1000-2340.2020.04.006
- Liu GD, Yang L, Song GH, Quan WJ, Lu GJ, Han XX, Shao LD (2000) Magnesium, calcium fertilizer effect on quality of feicheng peach and balanced fertilization research. J Shandong Agric Uni 2:173–176
- Liu H, Fan XM, Xiao Y, Long MF, Zeng XQ, Huang J, Liu LZ, Liu JQ, Zeng JF (2015) Compound biological organic fertilizer in citrus (Jinggang sweet pomelos) applied on the research and application. Agric Ext Serv 32:128
- Liu HL (2020) Effects of humic acid composite fertilizer applied on citrus "unblinded". Humic Acid 196(05):45-48. https://doi.org/ 10.19451/j.cnki.issn1671-9212.2020.05.007
- Liu HM, Yu HL, Shao W, Xu BB, Zhang ZH, Shi ZY, Zhao XF, Xu GY, Yang JH, Si P (2021) Effects of sorbitol and mannitol combined with NPK on the growth, fruit quality and nutrient absorption of peach. J Fruit Trees 38:911-921. https://doi.org/ 10.13925/j.cnki.gsxb.20210046
- Liu HW, Tan QL, Chen M, Zhuang ML, Li XB, Hu CX (2021) Phosphorus reduction with zinc fertilizer on the influence of the



pomelo fruit yield and quality. J Huazhong Agric Uni 40:70-76. https://doi.org/10.13300/j.cnki.hnlkxb.2021.01.008

- Liu JX, Li XF, Shi Y, Guo HL, Hou LP, Zhang Y (2019) Spraying on the leaf ecological nanometer selenium's influence on the quality of lettuce. Zhejiang Agric Sci 60(05):803-806. https://doi.org/10. 16178/j.issn.0528-9017.20190540
- Liu JY, Tian QL, Huang WH, Wu YY, Peng JY, Zhang YJ, Xie RL, Wei SL, Mou HF, Wei D (2021) Effects of selenium application on plant growth, physiology and fruit quality of three varieties of banana. Guanxi Inst Bot 42:1913–1920
- Liu LH, Zheng GP, Qian YD, Lv YD (2010) Effects of single and double row planting and fertilization on yield and quality of hybrid sweet sorghum. Henan Agric Sci 422(03):15-22. https://doi.org/ 10.15933/j.cnki.1004-3268.2010.03.014
- Liu LJ, Hong CL, Zhu FX, Yao YL, Chen XY, Wang WP (2017) Effects of organic and inorganic rehydration fertilizers on soil and citrus quality in mandarin orchards. J Zhejiang Agric Sci 58(07):1155-1165. https://doi.org/10.16178/j.issn.0528-9017.20170719
- Liu LM, Cao YJ, Sun A, Zhao HL, Nie L (2018) Different fertilization combinations communist-held areas of the yellow river is the growth and fruit quality of fuji apple tree body. Agric Sci Technol Comm 7:156–159
- Liu LM, Cao YJ, Sun A, Zhao HL, Nie L (2018) Effects of different fertilization combinations on the growth and fruit quality of Fuji apple trees in the Yellow River Gudao area. Bull Agric Sci Technol 7:156–159
- Liu N, Qu SN, Wang XG, Xie C, Gao SJ, Wang J, Yu HQ, Jiang CJ, Zhao XH, Zhao SL (2020) Effects of calcium molybdenum boron fertilizer on photosynthetic characteristics, yield and quality of peanut. J Shenyang Agric Uni 51:27–34
- Liu RF, Huang RH, Wang QY, Chen XR, Liu YM, Ma XF (2020) Effects of density and fertilization level on growth, development and yield of spring-sown buckwheat Buckwheat No. 2. Jiangsu Agric Sci 48(07):102-106. https://doi.org/10.15889/j.issn.1002-1302.2020.07.019
- Liu RG, Yuan ZQ, Jiang RQ, Xiao YP (2009) Effects of different bio organic fertilizers on physiological characteristics and main characters of Gannan navel orange. Jiangxi Agric J 21:57-58. https:// doi.org/10.19386/j.cnki.jxnyxb.2009.04.019
- Liu WJ, Jiang T, Lu SJ, He WH, Xiang TJ (2020) Application effect of special organic-inorganic compound fertilizer for citrus on newhall navel orange. Hunan Agric Sci 1:49-50. https://doi.org/ 10.16498/j.cnki.hnnykx.2020.001.012
- Liu XH (1987) Carbohydrates and citrus flowering and fruiting. Fujian Fruits. 59-60.
- Liu Y (2019) Organic fertilizer nitrogen to replace alternate root zone under drip irrigation water and nitrogen coupling effect influence on watermelon growth. Huaibei Normal Uni.
- Liu Y, Liu SJ, Zhang NZ, Zhang JA (1999) Effects of several plant growth regulators on flowering and fruit setting of navel orange. Jiangxi Forestry Sci Technol 2:2. https://doi.org/10.16259/j.cnki. 36-1342/s.1999.02.006
- Liu Y, Zhao KL, Qu MS, Jin LH, Chen J, Liao H (2021) Effects of basal fertilizer reduction on yield, quality and soil nutrients of lettuce for four consecutive years. Soil Fert China 5:185–191
- Liu YH, Y, Meng, A, Tang, XJ, Zhang, WJ, Dong, YC, Lai (2019) Agricultural organic waste fermentation CO<sub>2</sub> fertilization effect on yield and quality of lettuce. North Garden 14:12–18
- Liu YP, Zeng WG (1989) Ecological adaptability and main cultivation techniques of navel orange in Northwest Sichuan Basin. J Sichuan Agric Uni 2:65–70
- Liu YX, Wu B, Wang AB, Li C, Wang LX, He YD, Ju JJ, Wang BZ (2017) Organic and inorganic fertilizer for wax-apple growth, yield and quality. Fruit Trees Southern China 46(03):92-94. https://doi.org/10.13938/j.issn.1007-1431.20160300

- Liu ZB, Shu AP, Liu GR, Li ZZ, Zhang WX, Yuan FS, Hu QF (2018) Organic fertilizer instead of chemical fertilizer influence on yield and soil nutrient cropping. Jiangxi Agric J 30(11):35-39. https:// doi.org/10.19386/j.cnki.jxnyxb.2018.11.09
- Liu ZH, Jiang LH, Li XL, Hardter R, Zhang WJ, Zhang YL, Zhwng DF (2008) Effect of N and K fertilizers on yield and quality of greenhouse vegetable crops. Pedosphere 18:496–502. https://doi.org/10.1016/S1002-0160(08)60040-5
- Lu HJ, Zhai BN, Liu LL, Li TT, Cai JQ, Zhao ZY (2012) Effects of different fertilization patterns on growth, development, yield and quality of red Fuji apple under raw grass cover conditions. Northern Hortic 10:5–8
- Lu HJ, Zhai BN, Liu LL, Li TT, Cai JQ, Zhao ZY (2012) Grass coverage under the condition of different fertilization on the growth and development of fuji apple, the influence of yield and quality. North Garden 265(10):5–8
- Lu J (2021) Effects of Hefei on soil microorganisms, enzyme activities and cucumber quality in livestock manure group. Vegetable 4:19–23
- Lu KG, Zhu SH, Zhang LZ (2003) Organic fertilizer on soil physical and chemical properties and the influence of red fuji apple fruit quality. J Shihezi Uni 3:205-208. https://doi.org/10.13880/j.cnki. 65-1174/n.2003.03.010
- Lu M, Liang Y, Lakshmanan P, Guan X, Liu D, Chen X (2021) Magnesium application reduced heavy metal-associated health risks and improved nutritional quality of field-grown Chinese cabbage. Environ Pollut 289:117881. https://doi.org/10.1016/j.envpol. 2021.117881
- Lv FJ, Xiao YP, Wei LG, Wang RQ, Yuan ZQ, Lin HX (2016) The influence of chemical multi-topping for sesame seed yield and quality. Henan Agric Sci 45:10-14. https://doi.org/10.15933/j. cnki.1004-3268.2016.10.003
- Lv YD, Niu ZW, Li HY, Guo XH, Liu LH, Tong B, Zhang YM, Zheng GP (2009) Effects of fertilization amount on growth, development and yield of forage hybrid sweet sorghum. Heilongjiang Eight One Agric Reclam Uni Acad J 3:17–20
- Ma AP, Cui HH, Kang XL, Jing H, Wang YZ, Zhang JC (2021) Inorganic nitrogen and phosphorus reduction, applying organic fertilizer content effects on wheat quality traits. China Agric Notified 37:7–13
- Ma L, Zhang J, Ren R, Fan B, Hou L, Li J (2020) Effects of different organic nutrient solution formulations and supplementation on tomato fruit quality and aromatic volatiles. Arch Agron Soil Sci 67:563–575. https://doi.org/10.1080/03650340.2020. 1740208
- Ma RH, Yan XL, Jiang X, Wang RX, Guo YS, Zhang SS, Liu YS, Zhou HM, Wang QY, Wang CL, Huang XC (2021) Application of nitrification inhibitor containing ammonium nitrate urea cucumber yield and quality of the facilities. Shandong Agric Sci 53:100-103. https://doi.org/10.14083/j.issn.1001-4942.2021.03. 017
- Ma X, Liu ML, He X, Wang F, Zhang QP (2020) Effects of chemical fertilizer reduction combined with organic fertilizer on yield formation and rapeseed quality of rape. Crop Res 34:518-524. https://doi.org/10.16848/j.cnki.issn.1001-5280.2020.06.03
- Ma ZN (1988) Total nutrient solution concentration effects on yield and quality of tomato. Shanghai Veg 4:29–31
- Mahmud M, Abdullah R, Yaacob JS (2020) Effect of vermicompost on growth, plant nutrient uptake and bioactivity of ex vitro pineapple (*Ananas comosus* var. MD2). Agron 10:1333. https://doi.org/ 10.3390/agronomy10091333
- Malik AA, Chattoo MA, Sheemar G, Rashid R (2011) Growth, yield and fruit quality of sweet pepper hybrid SH-SP-5 (*Capsicum annuum* L.) as affected by integration of inorganic fertilizers and organic manures (FYM). J Agric Sci Technol 7:1037-1048. ISSN 1686-9141



- Manaf A, Raheel M, Sher A, Sattar A, Ul-Allah S, Qayyum A, Hussain Q (2019) Interactive effect of zinc fertilization and cultivar on yield and nutritional attributes of canola (*Brassica napus* L.). J Soil Sci Plant Nutr 19:671–677. https://doi.org/10.1007/s42729-019-00067-2
- Manzeke GM, Mtambanengwe F, Nezomba H, Mapfumo P (2014) Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. Field Crops Res 166:128–136. https://doi.org/10.1016/j.fcr.2014. 05.019
- Manzeke MG, Mtambanengwe F, Nezomba H, Watts MJ, Broadley MR, Mapfumo P (2017) Zinc fertilization increases productivity and grain nutritional quality of cowpea (*Vigna unguiculata* [L.] Walp.) under integrated soil fertility management. Field Crops Res 213:231–244. https://doi.org/10.1016/j.fcr.2017.08.010
- Marathe RA, Sharma J, Murkute AA, Babu KD (2017) Response of nutrient supplementation through organics on growth, yield and quality of pomegranate. Sci Hortic 214:114–121. https://doi.org/ 10.1016/j.scienta.2016.11.024
- Masroor HM, Anjum MA, Hussain S, Ejaz S, Ahmad S, Ercisli S, Zia-Ul-Haq M (2015) Zinc Ameliorates fruit yield and quality of mangoes cultivated in calcareous soils. Erwerbs-Obstbau 58:49–55. https://doi.org/10.1007/s10341-015-0258-2
- Mehrvarz S, Chaichi MR (2008) Effect of phosphate solubilizing microorganisms and phosphorus chemical fertilizer on forage and grain quality of barely (*Hordeum vulgare* L.). American-Eurasian J Agric Environ Sci 3:855-860. ISSN:1818-6769
- Mei F, Chen L, Ma WC, Liu T (2018) Effects of different nitrogen application rates on cucumber growth and quality in glass terraced greenhouse. Qinghai Agric Forestry Sci Technol 2:5–7
- Meng XG, Jiang YC, Liu JG, Luo F, Pei ZY (2011) Effects of fertilization on the quality shape of sweet sorghum stems of heavy stubble. Tianjin Agric Forestry Sci Technol 224(06):1-4. https:// doi.org/10.16013/j.cnki.1002-0659.2011.06.016
- Miao XY, Liang Y, Yang JQ, Gao XX, Hou LP (2021) Zinc iron with on cucumber growth, photosynthetic characteristics and fruit quality. J Northwest Agric 30:555–562
- Milošević T, Milošević N, Mladenović J (2022) The influence of organic, organo-mineral and mineral fertilizers on tree growth, yielding, fruit quality and leaf nutrient composition of apple cv. 'Golden Delicious Reinders'. Sci Hortic 297:110978. https://doi. org/10.1016/j.scienta.2022.110978
- Mo JS, Qu SH, Mei ZM, Zhang DN, He SK, Xiao YH, Zhu JJ (2018) Effect of shrimp skin bio organic fertilizer on improving fruit quality of sugar orange. Guangxi Hortic 29(06):28–30
- Moola R, Davari MR, Sharma SN (2014) Direct, residual and cumulative effects of organic manures and biofertilizers on yields, NPK uptake, grain quality and economics of wheat (*Triticum aestivum* L.) under organic farming of rice-wheat cropping system. J Org Syst 1177-4258. ISSN 1177-4258
- Mordoğan N, Hakerlerler H, Ceylan Ş, Aydın Ş, Yağmur B, Aksoy U (2013) Effect of organic fertilization on fig leaf nutrients and fruit quality. J Plant Nutr 36:1128–1137. https://doi.org/10.1080/ 01904167.2013.780611
- Moss GI, Higgins ML (1974) Magnesium influences on the fruit quality of sweet orange (*Citrus sinensis* L. osbeck). Plant Soil 41:103–112. https://doi.org/10.1007/BF00017948
- Mu LH, Yan KJ, Chen CJ, Chang KQ, Zhou HL, Yang CL (2012) Effects of different densities and fertilization levels on buckwheat yield and its structure. Mod Agric Sci Technol 567(01):63–64
- Mubarak MU, Kiran A, Shahzad AN, Qayyum MF, Ishfaq M, Mahmood K, Wakeel A (2022) Mineral biofortification of vegetables through soil-applied poultry mortality compost. Plos One 17:e0262812. https://doi.org/10.1371/journal.pone.0262812

- Murmu K, Ghosh BC, Swain DK (2013) Yield and quality of tomato grown under organic and conventional nutrient management. Arch Agron Soil Sci 59:1311–1321. https://doi.org/10.1080/ 03650340.2012.711472
- Mustafa HMM, Spyridon AP, Maha MEA (2021) The application of nitrogen fertilization and foliar spraying with calcium and boron affects growth aspects, chemical composition, productivity and fruit quality of strawberry plants. Hortic 7:257. https://doi.org/ 10.3390/horticulturae7080257
- Nadeem F, Farooq M, Mustafa B, Rehman A, Nawaz A (2020) Residual zinc improves soil health, productivity and grain quality of rice in conventional and conservation tillage wheat-based systems. Crop Pasture Sci 71:322. https://doi.org/10.1071/CP19353
- Nadeem F, Farooq M, Ullah A, Rehman A, Nawaz A, Naveed M (2019) Influence of Zn nutrition on the productivity, grain quality and grain biofortification of wheat under conventional and conservation rice-wheat cropping systems. Arch Agron Soil Sci 66:1042– 1057. https://doi.org/10.1080/03650340.2019.1652273
- Nava G, Dechen AR, Nachtigall GR (2007) Nitrogen and potassium fertilization affect apple fruit quality in Southern Brazil. Arch Agron Soil Sci 39:96–107. https://doi.org/10.1080/0010362070 1759038
- Negi YK, Sajwan P, Uniyal S, Mishra AC (2021) Enhancement in yield and nutritive qualities of strawberry fruits by the application of organic manures and biofertilizers. Sci Hortic 283:110038. https://doi.org/10.1016/j.scienta.2021.110038
- Nie J, Tan Z, Dai XZ, Huang K (2021) NPK with effects on hot pepper production, quality. Chinese Veg 34:80-87. https://doi.org/10. 16861/j.cnki.zggc.2021.0267
- Ning Y, Feng D, Deng YY, Xuan WY (2020) Effects of fertilizer reduction on fruit development and quality traits of banana. South China Fruits 49:61-64. https://doi.org/10.13938/j.issn.1007-1431.20190425
- Niu RF, Guo R (2016) The influence of different organic fertilizers on the quality of Fuji apple. Chinese Forest Byproducts 142(03):33-36. https://doi.org/10.13268/j.cnki.fbsic.2016.03.011
- Noha AM (2018) Promising impacts of humic acid and some organic fertilizers on yield, fruit quality and leaf mineral content of wonderful pomegranate (*Punica granatum* L.) Trees. Egypt J Hort 45:105-119. https://doi.org/10.21608/ejoh.2018.3495.1061
- O'Leary MJ, Rehm GW (1990) Nitrogen and sulfur effects on the yield and quality of corn grown for grain and silage. J Prod Agric 3:135. https://doi.org/10.2134/jpa1990.0135
- Ochoa-Velasco CE, Valadez-Blanco R, Salas-Coronado R et al (2016) Effect of nitrogen fertilization and *Bacillus licheniformis* biofertilizer addition on the antioxidants compounds and antioxidant activity of greenhouse cultivated tomato fruits (*Solanum lycopersicum* L. var. Sheva). Sci Hortic 201:338–345. https://doi.org/ 10.1016/j.scienta.2016.02.015
- Olaniyi JO, Adelasoye KA, Jegede CO (2008) Influence of nitrogen fertilizer on the growth, yield and quality of grain amaranth varieties. World J Agric Sci 4:506-513. ISSN: 1817-3047
- Olesen JE, Askegaard M, Rasmussen IA (2009) Winter cereal yields as affected by animal manure and green manure in organic arable farming. Eur J Agron 30:119–128. https://doi.org/10.1016/j.eja. 2008.08.002
- Orlovius K, McHoul J (2015) Effect of two magnesium fertilisers on leaf magnesium concentration, yield, and quality of potato and sugar beet. J Plant Nutr 38:2044–2054. https://doi.org/10.1080/ 01904167.2014.958167
- Oshundiya FO, Olowe VIO, Sowemimo FA, Odedina JN (2014) Seed yield and quality of sunflower (*Helianthus annuus* L.) as influenced by staggered sowing and organic fertilizer application in the humid tropics. Helia 37:237–255. https://doi.org/10.1515/ helia-2014-0012



- Osman SM, Abd El-Rhman IE (2010) Effect of organic and bio N-fertilization on growth, productivity of fig tree (*Ficus Carica*, L.). Res J Agric Biol Sci 6:3195–328
- Öztürk Ö (2010) Effects of source and rate of nitrogen fertilizer on yield, yield components and quality of winter rapeseed (*Brassica napus* L.). Chil J Agric Res 70:132–141. https://doi.org/10.4067/ S0718-58392010000100014
- Pal SK, Sasmal S (2019) Influence of integrated nutrition on yield, nutrient uptake and quality of aromatic rice in an Inceptisol. Agric Res 9:197–202. https://doi.org/10.1007/ s40003-019-00418-6
- Pan YX, Cheng HJ, Wang LX, Ge ZY, Sui HJ, Yu DW, Zhang S, Liu C (2021) Effects of different fertilization amounts and planting densities on agronomic traits and broom yield of broom sorghum. Northeast Agric Sci 46(02):19-22. https://doi.org/10.16423/j. cnki.1003-8701.2021.02.006
- Pang T, Liang JJ, Yao N, Yi XF, Pang ZW, Qiu JH, Cao HH, Cao YH (2021) Study on quality effect of banana stalk and leaf silage treated by different bacteria: Feed Res 42:38-40. https://doi.org/ 10.13557/j.cnki.issn1002-2813.2021.20.016
- Paul KB, Grace TO, Ngozi EA, Simon U (2016) Poultry manure influenced growth, yield and nutritional quality of containerized aromatic pepper (*Capsicum annuum* L., var Nsukka Yellow). Afr J Agric Res 11:2013–2023. https://doi.org/10.5897/AJAR2015. 10512
- Peck NH, Grunes DL, Welch RM, MacDonald GE (1980) Nutritional quality of vegetable crops as affected by phosphorus and zinc fertilizers. Agron J 72:528. https://doi.org/10.2134/agronj1980. 00021962007200030028x
- Pen JM, Zhou HS, Yang XH, Yang C, Li DJ, Wang Y, Shi J, Peng Y (2018) Effects of special fertilizer for yak dung on ponkan synthetic quality. Zhejiang Citrus 35(01):10-14. https://doi.org/10. 13906/j.cnki.zjgj.1009-0584.2018.01.649
- Peng XX, Guo Z, Zhang YJ, Li J (2018) Long-term organic manure and chemical fertilizer on Weibei rainfed highland with HanYuan apple orchards water productivity and quantitative simulation the influence of soil organic carbon content. J Plant Nutr Fert 24(01):33–43
- Peng ZP, Wu XN, Yu JH, Huang JC, XU PZ (2013) Effects of potassium application on nutrient absorption, yield and quality of peanut. J Peanut Sci 42(03):27-31. https://doi.org/10.14001/j.issn. 1002-4093.2013.03.005
- Peng ZP, Yang SH, Cao JX, Zhang JP, Huang JW, Huang YL (2007) Effect of microbial fluid fertilizer on yield and quality of banana. Guangdong Agric Sci 2:11-12. https://doi.org/10.16768/j.issn. 1004-874x.2007.02.004
- Pérez-Murcia MD, Bustamante MÁ, Orden L, Rubio R, Agulló E, Carbonell-Barrachina ÁA, Moral R (2021) Use of agri-food composts in almond organic production: effects on soil and fruit quality. Agron 11:536. https://doi.org/10.3390/agronomy11030536
- Perry LJ, Olson RA (1975) Yield and quality of corn and grain sorghum grain and residues as influenced by N fertilization 1. Agron J 67:816–818. https://doi.org/10.2134/agronj1975.0002196200 6700060023x
- Petropoulos SA, Fernandes Â, Xyrafis E, Polyzos N, Antoniadis V, Barros L, CFR Ferreira I (2020) The optimization of nitrogen fertilization regulates crop performance and quality of processing tomato (*Solanum lycopersicum* L. cv. Heinz 3402). Agron 10:715. https://doi.org/10.3390/agronomy10050715
- Poberezny J, Wszelaczynska E, Keutgen AJ (2012) Yield and chemical content of carrot storage roots depending on foliar fertilization with magnesium and duration of storage. J Elem 17:479–494. https://doi.org/10.5601/jelem.2012.17.3.10
- Polat E, Demir H, Onus AN (2008) Comparison of some yield and quality criteria in organically and conventionally-grown lettuce. Afr J Biotechnol 7:1235–1239. https://doi.org/10.5897/AJB07.649



- Pu YY, Lv XM, Wu MC, Wang DS, Li WM, Wang SQ, Li HX, Hu F, Jiao JG (2017) Under the condition of fumigation, partly replace organic manure fertilizer in watermelon growth and nutrient utilization. J Soil Water Conserv 31(06):306-311. https://doi.org/ 10.13870/j.cnki.stbcxb.2017.06.048
- Qi JX, Zhang RS (2019) Different quantity of silicon fertilizer on grain yield and quality of the sunflower. J Inner Mongolia Agric Uni 41:14-18. https://doi.org/10.16853/j.cnki.1009-3575.2020.01.003
- Qin DM, He J, Li YP, Feng D, Deng YY, Xuan WY (2021) Effects of spraying plant growth regulator on fruit growth and quality of dwarf banana. South China Fruits 50:45-50. https://doi.org/ 10.13938/j.issn.1007-1431.20200544
- Qing LJ, Zhang RB, Xue SW, Yu FX, Shan M, Li Y, Guo CQ, Li JW (2021) New type biological pesticide effect on cucumber powdery mildew control effect and quality of cucumber. Mod Agric Sci Technol 9:98–101
- Qiu X, Wang Y, Hu G, Wang Q, Zhang X, Dong Y (2013) Effect of different fertilization modes on physiological characteristics, yield and quality of Chinese cabbage. J Plant Nutr 36:948–962. https://doi.org/10.1080/01904167.2012.7572
- Qu JF, Zhao FJ, Fu SB (2010) Study on effects of different nitrogen fertilizers applied to bananas. Guangdong Agric Sci 37(09):116-117. https://doi.org/10.16768/j.issn.1004-874x.2010.09.069
- Qu Z, Qi X, Shi R, Zhao Y, Hu Z, Chen Q, Li C (2020) Reduced N fertilizer application with optimal blend of controlled-release urea and urea improves tomato yield and quality in greenhouse production system. J Soil Sci Plant Nutr 20:1741–1750. https:// doi.org/10.1007/s42729-020-00244-8
- Quddus MA, Siddiky MA, Hussain MJ, Rahman MA, Ali MR, Masud MAT (2021) Magnesium influences growth, yield, nutrient uptake, and fruit quality of tomato. Int J Veg Sci 28:441–464. https://doi.org/10.1080/19315260.2021.2014614
- Quezada JC, Lenssen AW, Moore KJ, Sawyer JE, Summer P (2015) Amino acid biosynthesis byproducts are a suitable source of nitrogen for corn production. Field Crops Res 184:123–132. https://doi.org/10.1016/j.fcr.2015.09.014
- Raese JT, Drake SR, Curry EA (2007) Nitrogen fertilizer influences fruit quality, soil nutrients and cover crops, leaf color and nitrogen content, biennial bearing and cold hardiness of 'golden delicious.' J Plant Nutr 30:1585–1604. https://doi.org/10.1080/01904 160701615483
- Ram M, Davari MR, Sharma SN (2014) Direct, residual and cumulative effects of organic manures and biofertilizers on yields, NPK uptake, grain quality and economics of wheat (*Triticum aestivum* L.) under organic farming of rice-wheat cropping system. J Org Syst 9:1177-4258. ISSN: 1177-4258
- Ramzan Y, Hafeez MB, Khan S, Nadeem M, S, Rahman, S, Batool, J, Ahmad (2020) Biofortification with zinc and iron improves the grain quality and yield of wheat crop. Int J Plant Prod 14:501– 510. https://doi.org/10.1007/s42106-020-00100-w
- Rao ZH, Cai Y, Liao TJ (1997) Three yuan into the influence of the quality of compound fertilizer on tomato physiological characteristics and yield. J Southwest Agric Uni 6:81–84
- Reddy SBP, Madhuri KVN, Venkaiah K, Prathima T (2016) Effect of nitrogen and potassium on yield and quality of pearl millet (*Pennisetum glaucum* L.). Int J Agric Innov Res 4:2319-1473. ISSN: 2319-1473
- Rehim A, Khan M, Imran M, Bashir MA, Khan SUA, Naeem M, Mubshar H (2020) Integrated use of farm manure and synthetic nitrogen fertilizer improves nitrogen use efficiency, yield and grain quality in wheat. Ital J Agron 15:29–34. https://doi.org/ 10.4081/ija.2020.1360

- Rekowski A, Wimmer MA, Hitzmann B, Hermannseder B, Hahn H, Zörb C (2020) Application of urease inhibitor improves protein composition and bread-baking quality of urea fertilized winter wheat. J Soil Sci Plant Nutr 183:260–270. https://doi.org/10. 1002/jpln.201900529
- Ren SP, Wang F, Yao HR, Dai YL (2018) Basal organic substitution effect on yield and quality of watermelon. Zhejiang Agric Sci 59:2034-2037. https://doi.org/10.16178/j.issn.0528-9017.20181126
- Riahi A, Hdider C, Sanaa M, Tarchoun N, Ben KM, Guezal I (2009) Effect of conventional and organic production systems on the yield and quality of field tomato cultivars grown in Tunisia. J Sci Food Agric 89:2275–2282. https://doi.org/10.1002/jsfa.3720
- Rose T, Kretzschmar T, Liu L, Lancaster G, Wissuwa M (2016) Phosphorus deficiency alters nutrient accumulation patterns and grain nutritional quality in rice. Agron 6:52. https://doi.org/10.3390/ agronomy6040052
- Roussos PA, Gasparatos D (2009) Apple tree growth and overall fruit quality under organic and conventional orchard management. Sci Hortic 123:247–252. https://doi.org/10.1016/j.scienta.2009. 09.011
- Ruan J, Ma L, Shi Y (2013) Potassium management in tea plantations: Its uptake by field plants, status in soils, and efficacy on yields and quality of teas in China. J Soil Sci Plant Nutr 176:450–459. https://doi.org/10.1002/jpln.201200175
- Ryan M, Derrick J, Dann P (2004) Grain mineral concentrations and yield of wheat grown under organic and conventional management. J Sci Food Agric 84:207–216. https://doi.org/10.1002/jsfa.1634
- Saha S, Gopinath KA, Mina BL, Gupta HS (2008) Influence of continuous application of inorganic nutrients to a maize-wheat rotation on soil enzyme activity and grain quality in a rainfed Indian soil. Eur J Soil Biol 44:521–531. https://doi.org/10.1016/j.ejsobi. 2008.09.009
- Sayğı H (2021) Effects of green manure and poultry manure on strawberry production. IJROWA 10:439-448. https://doi.org/10.30486/ ijrowa.2021.1910637.1139
- Sete PB, Comin JJ, Nara CM et al (2019) Nitrogen fertilization affects yield and fruit quality in pear. Sci Hortic 258:108782. https://doi. org/10.1016/j.scienta.2019.108782
- Shahid M, Saleem MF, Khan HZ, Wahid MA, Sarwar M (2015) Improving wheat (*Triticum aestivum* L.) yield and quality by integration of urea with poultry manure. Soil Environ 34:148-155. ISSN: 2075-1141
- Shang XL (2020) Effects of different chemical flower thinning agents on fruit setting rate and fruit quality in peach. Nonwood Forest Res 38:222-227. https://doi.org/10.14067/j.cnki.1003-8981.2020.02.028
- Shang XLZhang JP, Li H, Wang LR, Yang PX (2018) Effects of different fertilization methods on growth of peach and soil nutrients. Nonwood Forest Res 36:172-175. https://doi.org/10.14067/j.cnki. 1003-8981.2018.03.027
- Shen B, Hu AT, Guo Q, Yang J (1999) Fertilizer after the dosage of the influence of substrate cultivation yield and quality of tomato. Chinese Veg 2:1
- Shen FK, Huang JP, Li LX, He M, Guo ZR, Zhao FZ, Liao ML (2011) Study on formula fertilization of Pomelo in tidal soil area. Anhui Agric Sci 39:2135-2137. https://doi.org/10.13989/j.cnki.0517-6611.2011.04.200
- Shen XJ, Qiu JY, Zhu LQ, Zhang XY, Cao L, He YZ, Peng LZ, Chun CP (2021) Effects of potassium chloride application on chloride accumulation in soil-navel orange trees and leaf nutrition and fruit quality. Plant Nutr Fert Science 27:858–868
- Sheng LJ, Shi JQ, Lu ML, Jiang YN, Zeng PF (1992) Experiment on improving the fruit rate of navel orange with gibberellin and superk. Guangxi Citrus 0:14-16.
- Sheng YN, Yang YJ, Chen LP (2019) Spraying on the leaf of amino acid water soluble fertilizer influence on yield and quality of lettuce. Liaoning Prov Agric Sci 308(04):29–31

- Shi DL, Wang XL, Liu AK, Hou ZF, Liang GT (2021) Yellow soil paddy soil microbial biomass carbon and nitrogen and rice quality of biochar with nitrogen response. Environ Sci 42(01):443-449. https://doi.org/10.13227/j.hjkx.202005186
- Shi YZ, Cao H, Yang HT, Li P, Hu YL (2014) Effects of spraying micro fertilizer on yield and quality of peanut leaves. Bull Agric Sci Technol 509(05):75–77
- Shi YZ, Yang HT, Cao H (2015) Effects of increasing silicon fertilizer on yield, characters and quality of peanut. Bull Agric Sci Technol 2:89–91
- Shivay YS, Kumar D, Prasad R (2008) Effect of zinc-enriched urea on productivity, zinc uptake and efficiency of an aromatic rice-wheat cropping system. Nutr Cycl Agroecosystems 81:229–243. https:// doi.org/10.1007/s10705-007-9159-6
- Shivay YS, Kumar D, Prasad R (2008) Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice-wheat cropping system. Commun Soil Sci Plant Anal 39:1154–1167. https://doi.org/10. 1080/00103620801925869
- Simić M, Dragičević V, Mladenović DS, Vukadinović J, Kresović B, Tabaković M, Brankov M (2020) The contribution of soil tillage and nitrogen rate to the quality of maize grain. Agron 10:976. https://doi.org/10.3390/agronomy10070976
- Singer JW, Kohler KA, Liebman M, Richard TL, Cambardella CA, Buhler DD (2004) Tillage and compost affect yield of corn, soybean, and wheat and soil fertility. Agron J 96:531. https://doi.org/ 10.2134/agronj2004.5310
- Singh SR, Zargar MY, Najar GR, Peer FA, Ishaq MI (2011) Integrated use of organic and inorganic fertilizers with bio-inoculants on yield, soil fertility and quality of apple (*Malus domestica*). J Indian Soc Soil Sci 59:262–267
- Singh V, Dubey YP, Paul V (2018) Impact of nutrients from organic and inorganic sources on yield attributes, yield and quality in sesamum-pea cropping sequence in an acid Alfisol. J Pharmacogn Phytochem 7:1448-1453. ISSN: 2278-4136
- Singh YV, Singh KK, Sharma SK (2013) Influence of crop nutrition on grain yield, seed quality and water productivity under two rice cultivation systems. Rice Sci 20:129–138. https://doi.org/ 10.1016/S1672-6308(13)60113-4
- Smitha GR, Basak BB, Thondaiman V, Saha A (2019) Nutrient management through organics, bio-fertilizers and crop residues improves growth, yield and quality of sacred basil (*Ocimum* sanctum Linn). Ind Crops Prod 128:599–606. https://doi.org/10. 1016/j.indcrop.2018.11.058
- Snehangshu SN, Brahmachari K, Chowdhury MR (2014) Integrated approach in nutrient management of sesame with special reference to its yield, quality and nutrient uptake. Bioscan 9:101–105
- Song HY, Chen D, Tu MY, Li J, Sun SX, Liu CY, Jiang GL (2020) Effects of applying bag-controlled release fertilizer for years on growth, yield and quality of peach. Southwest China J Agric 33:104-108. https://doi.org/10.16213/j.cnki.scjas.2020.1.017
- Souza EJ, Martin JM, Guttieri MJ, O'Brien KM, Habernicht DK, Lanning SP, McLean R, Carlson GR, Talbert LE (2004) Influence of genotype, environment, and nitrogen management on spring wheat quality. Crop Sci 44:425–432. https://doi.org/10.2135/ cropsci2004.4250
- Staugaitis G, Narutytė I, Arbačauskas J, Vaišvila Z, Rainys K, Mažeika R, Masevičienė A, Žičkienė L, Šumskis D (2016) The influence of composts on yield and chemical elements of winter wheat and spring barley. Zemdirbyste-Agriculture 103:355-362. https://doi.org/10.13080/z-a.2016.103.045
- Stojanov D, Milošević T, Mašković P, Milošević N, Glišić I, Paunović G (2019) Influence of organic, organo-mineral and mineral fertilisers on cane traits, productivity and berry quality of red raspberry (*Rubus idaeus* L.). Sci Hortic 252:370–378. https://doi.org/ 10.1016/j.scienta.2019.04.009



- Sui HJ, Cheng HJ, Wang LX, Ge ZY, Zhang S, Pan YX, Sun YQ, Chen L (2018) Effects of different fertilization methods on sorghum yield and efficiency. Northern J Agric Sci 46(02):47–50
- Suja G, Sundaresan S, John KS, Sreekumar J, Misra RS (2011) Higher yield, profit and soil quality from organic farming of elephant foot yam. Agron Sustain Dev 32:755–764. https://doi.org/10. 1007/s13593-011-0058-5
- Sun LQ, Gu XH, Zhang JL, Liu C, Gao B, Sun QZ, Wang YY, Wei TT, Li XD (2014) Effects of zinc fertilizer on physiological characteristics, yield and quality of peanut. J Peanut Sci 43(01):1-6. https://doi.org/10.14001/j.issn.1002-4093.2014.01.013
- Sun YX, Wang MW (2019) Effects of organic-inorganic compound fertilizer on growth and quality of peanut. Soils 51:910-915 https:// doi.org/10.13758/j.cnki.tr.2019.05.010
- Suo YY, Zhang X, Si XZ, Yu Q, Mao JW, Li L, Wang YN, Yu H (2018) Effects of combined application of phosphorus and zinc on physiological characteristics, yield and quality of peanut. Soil Fert Sci China 2:96–102
- Suo YY, Zhang X, Si XZ, Yu Q, Mao JW, Li L, Wang YN, Yu H (2018) Zinc phosphate with impact on peanut physiological characteristics, yield and quality. Soil Fert China 2:274(02):96-102.
- Tang CC, Luo F, Gao JM, Pei ZY, Li XY, Sun SJ (2014) Effects of saline-alkali soil fertilization on biological yield, sugar hammerness and related traits of sweet sorghum. Heilongjiang Agric Sci 241(07):46–50
- Tang D, Xie YR, Zhang P, Cui YM, Gui RQ, Qin Y (2021) Different fertilizer amount in matrix effects on eggplant hole tray seedling growth. China Cucurbits Veg 34:83-87. https://doi.org/10. 16861/j.cnki.zggc.2021.0091
- Tang XQ, Su H, Li M, Zhang MF, Huang JR, Li JC, Song YH, Li JP (2021) Before filling stage heat spraying on the leaf spray effect on wheat yield and grain quality. J Anhui Agric Uni 48:707-712. https://doi.org/10.13610/j.cnki.1672-352x.20211105.005
- Tang Y, Pang ZP, Zhu JN, Li YP, Wang YX, Liu Y (2020) Different applying manure, organic fertilizer content on the impact of greenhouse cucumber yield and quality. Shanxi Agric Sci 46:1816–1819
- Tang YX, Meng CX (1996) The influence of different varieties of potash fertilizer on tomato yield and quality. Soil Fert 3:2
- Tao YB, Zhang RL, Zhang Z (2019) Organic alternative, fertilizer nutrient regulation of soil physical and chemical properties, the influence of loquat fruit quality and yield. Zhejiang Agric Sci 60(09):1540-1543. https://doi.org/10.16178/j.issn.0528-9017. 20190916
- Thayamini HS (2018) Effects of inorganic and organic nutrients combindly used on yield and quality of groundnut (*Arachis hypogaea* L.). Bangladesh J Sci Ind Res 53:289–296. https:// doi.org/10.3329/bjsir.v53i4.39193
- Thiyagarajan C (2021) Organo zinc chelates for improving the yield and zinc nutrition of hybrid tomato on calcareous soil under drip fertigation. J Soil Sci Plant Nutr 22:140–149. https://doi.org/10. 1007/s42729-021-00639-1
- Tian C, Peng JW, Song HX, Rong XM, Guan CY, Liu Q (2012) Effects of combined application of organic fertilizer and chemical fertilizer on nutrient absorption, grain yield and quality of winter rape. Soil Fert Sci China 4:70–74
- Tian C, Peng JW, Song HX, Rong XM, Guan CY, Liu Q (2012) Organic fertilizer NPK nutrient uptake of winter rapeseed, the influence of the grain yield and quality. Soil Fert China 240(04):70–74
- Tobechi O, Victor O, Thomas F, Adeniyi S (2019) Organic fertilizers improve the growth, seed quality and yield of newly released soybean (*Glycine max* (L.) Merrill) varieties in the tropics. Org Agric 10:155–170. https://doi.org/10.1007/s13165-019-00258-2
- Tong X, Xu M, Wang X, Bhattacharyya R, Zhang W, Cong R (2014) Long-term fertilization effects on organic carbon fractions in a

red soil of China. CATENA 113:251–259. https://doi.org/10. 1016/j.catena.2013.08.005

- Torstensson G, Aronsson H, Bergström L (2006) Nutrient use efficiencies and leaching of organic and conventional cropping systems in sweden. Agron J 98:603. https://doi.org/10.2134/agronj2005. 0224
- Tsai CY, Dweikat I, Huber DM, Warren HL (1992) Interrelationship of nitrogen nutrition with maize (*Zea mays*) grain yield, nitrogen use efficiency and grain quality. J Sci Food Agric 58:1–8. https:// doi.org/10.1002/jsfa.2740580102
- Uddin M, Hussain S, Khan MMA, Hashmi N, Idrees M, Naeem M, Dar Tariq A (2014) Use of N and P biofertilizers reduces inorganic phosphorus application and increases nutrient uptake, yield, and seed quality of chickpea. Turk J Agric For 38:47–54. https://doi. org/10.3906/tar-1210-36
- Ullah A, Farooq M, Nadeem F, Rehman A, Hussain M, Nawaz A, Naveed M (2020) Zinc application in combination with zinc solubilizing *Enterobacter* sp. MN17 improved productivity, profitability, zinc efficiency, and quality of desi chickpea. J Soil Sci Plant Nutr 20:2133–2144. https://doi.org/10.1007/ s42729-020-00281-3
- Velmurugan A, Swarnam P (2017) Nutrient uptake and residual effect of organic treatments applied to vegetable-rice system in an acid soil. J Plant Nutr 40:1755–1772. https://doi.org/10.1080/01904 167.2016.1236944
- Verstraeten LMJ, Livens J (1975) Effect of slow-release nitrogenous fertilizers on growth. yield and quality of winter wheat. J Soil Sci Plant Nutr 138:435–446
- Wafula W, Korir N, Ojulong H, Siambi M, Gweyi-Onyango J (2018) Protein, calcium, zinc, and iron contents of finger millet grain response to varietal differences and phosphorus application in Kenya. Agron 8:24. https://doi.org/10.3390/agronomy8020024
- Walli S, Hafiz IA, Khan RI, Bashir MA, Uddin S, Khan SU, Ajmal U, Hussain S, Khalid MF (2021) Zinc and boron application at different phenological stages alleviates tree growth, fruit yield and quality of sweet orange Cv. 'Blood Red.' Gesunde Pflanz 74:385–396. https://doi.org/10.1007/s10343-021-00616-9
- Wang BH, Chen LN, Liu XC (2014) Optimization of fertilizer on grain yield and quality of peach, plum, apricot. Jiangsu Agric Sci 42:152-154. https://doi.org/10.15889/j.issn.1002-1302.2014. 08.227
- Wang BW, Chen YL, Zhu GP, Wang X, Yang Y, Liu JW (2021) Effects of foliar calcium chloride spray on the growth physiology of hydroponic lettuce in the high temperature season in Hainan. Chinese Melon Dish 34(04):94-98. https://doi.org/10.16861/j. cnki.zggc.2021.0093
- Wang C, Lv J, Coulter JA et al (2020) Slow-release fertilizer improves the growth, quality, and nutrient utilization of wintering Chinese chives (*Allium tuberosum* Rottler ex Spreng.). Agron 10:381. https://doi.org/10.3390/agronomy10030381
- Wang C, Wei JP, Wang P, Xie HL, Du JD, Zhao CJ, Wang ZH, Tang CS, Yang KJ (2015) Effects of fertilizer density factors on the yield and quality of sorghum 44 in semi-arid areas of Heilongjiang Province. Heilongjiang Eight One Agric Reclam Uni Acad J 27(05):20–24
- Wang CY, Zhang WX, Zhao L, Zhao XZ, Hou WP, Gao LW, Wang BL (2010) NPK fertilizer on rice yield and quality. Jilin Agric Sci 35(01):28-33. https://doi.org/10.16423/j.cnki.1003-8701. 2010.01.012
- Wang F, Li QH, Li Y (2003) Organic-inorganic fertilizer at the beginning of the effect on the loquat. Fujian Fruit Trees 1:3–4
- Wang F, Wang X, Song N (2021) Biochar and vermicompost improve the soil properties and the yield and quality of cucumber (*Cucumis sativus* L.) grown in plastic shed soil continuously cropped for different years. Agric Ecosyst Environ 315:107425. https://doi.org/10.1016/j.agee.2021.107425



- Wang GL, Kou XM, Zhang JH, Wang SH, Xu R, Han GM, Tang HJ, Zhu LY, Bi JH, Wu LM (2018) Biogas slurry instead of nitrogen fertilizer on rice growth and the influence of rice quality. Ecol Magazine 37(09):2672-2679. https://doi.org/10.13292/j.1000-4890.201809.017
- Wang GY, Xiao RX, Wu QS (2006) Effects of GA3 and bagging on fruit quality of red flesh navel orange. Anhui Agric Sci 19:4912-4913. https://doi.org/10.13989/j.cnki.0517-6611.2006.19.047
- Wang H, Li XX, Wang YL, Liu WJ, Lu XJ, Li BW (2021) Chemical fertilizers with organic fertilizer and reducing bacteria agent of hot pepper production, quality and nutrient accumulation. North Garden 16:1–7
- Wang H, Zhao XZ, Zhao K, Zhou JL, Ma YH (2021) Effect of applying biological fungus fertilizer + bag-controlled slow-release fertilizer in Taoyuan. Serv Agric Technol 38:22–24
- Wang J, Fu P, Lu W, Lu D (2020) Application of moderate nitrogen levels alleviates yield loss and grain quality deterioration caused by post-silking heat stress in fresh waxy maize. Crop J 8:1081–1092. https://doi.org/10.1016/j.cj.2019.11.007
- Wang J, Xiao Y, Zhang GH, Li X, Liu R, Hu YG (2021) Nitrogen and phosphorus control effects on hybrid rice yield and quality. Guangdong Agric Sci 48(08):131-138. https://doi.org/10. 16768/j.issn.1004-874X.2021.08.016
- Wang JS, Dong EW, Wu AL, Bai WB, Wang Y, Jiao XY (2019) Effects of fertilization under different fertility conditions on yield, quality and nutrient uptake and utilization of granular sorghum. China Agric Sci 52(22):4166–4176
- Wang JZ, Zhang Q, Gao ZX, Ma XQ, Qu F, Hu XH (2021) Two kinds of microbial agents on organic matrix bag autumn cucumber yield, quality and the influence of the rhizosphere environment. China Agric Sci 54:3077–3087
- Wang KJ, Han X, Zhang ZC, Zhu ZY, Tan QL, Hu CX (2018) Effects of recommended fertilization on the quality and slagging of 'Wenzhou Mandarin' and 'Nanfeng Mandarin'. J Fruit Sci 35(10):1190-1196. https://doi.org/10.13925/j.cnki.gsxb.20170 485
- Wang LN, Chang XH, Wang DM, Tao ZQ, Wang YJ, Yang YS, Zhao GC (2019) Effects of topdressing borax fertilizer on wheat yield and quality under different soil conditions. Crops 6:94-98. https://doi.org/10.16035/j.issn.1001-7283.2019.06.015
- Wang N, Jiao XY, Wu AL, Wang JS, Dong EW, Guo J, Ding YC, Wang LG (2016) Effects of biochar and fertilization on soil environment and sorghum yield and quality. Shanxi Agric Sci 44(11):1633–1637
- Wang P, Cui H, Chen M, Tan QL, Hu CX (2021) Special fertilizer with planting smooth vetch can improve citrus quality and nutrient efficiency. Soil Fert China 3:178–186
- Wang R, An JW, Zhang SY, Xin YH, Ji XJ (1999) Effects of calcium application on yield, quality and distribution of calcium in peanut plants. J Shenyang Agric Uni 4:437–439
- Wang R, An JW, Zhang SY, Xin YH, Yang H (1998) Effects of sulfur application on yield, quality and sulfur accumulation in peanut plants. Chinese J Soil Sci 4:34-35. https://doi.org/10.19336/j. cnki.trtb.1998.04.012
- Wang S, Tian X, Li M, Ni Y, Li J, Li H, Wang S, Chen Y, Guo C, Zhao A (2014) Water and nitrogen management on micronutrient concentrations in winter wheat. Agron J 106:1003. https:// doi.org/10.2134/agronj13.0354
- Wang SP, Du L, Hong J, Huang X, Zhang GY, Zhang LH, Lian ZC, Ye LX, Jiang L, Chen G (2020) Effects of combined application of organic and inorganic potassium fertilizer on yield, quality and soil condition of lettuce. Hubei Agric Sci 59(17):49-53. https://doi.org/10.14088/j.cnki.issn0439-8114. 2020.17.011
- Wang X, Liu S, Yin X et al (2020) Maize grain composition with additions of NPK briquette and organically enhanced N

fertilizer. Agron 10:852. https://doi.org/10.3390/agronomy10 060852

- Wang X, Liu W, Li Z, Teng Y, Christie P, Luo Y (2017) Effects of long-term fertilizer applications on peanut yield and quality and on plant and soil heavy metal accumulation. Pedosphere 30:555– 562. https://doi.org/10.1016/S1002-0160(17)60457-0
- Wang XW, Yang KY, Cha ZZ, Yang HZ, Hua YG, Guo PT (2018) Effects of different fertilization modes on yield and quality of pitaya fruit. Chinese J Trop Agric 38(05):8–13
- Wang Y, Shang QY, Yang XX (2021) Effects of combined application of nitrification inhibitors on yield and quality of tangerine and navel orange. Soil Fert China 2:206–212
- Wang Y, Shang QY, Yang XX (2021) Effects of nitrifying inhibitors on yield and quality of tangerine and navel orange. Soil Fert China 2:206–212
- Wang YL, Liu JY, Dai QL (1992) Study on nitrogen and phosphorus content and fertilization indexes of buckwheat plants. North China J Agric Sci 2:71–76
- Wang YM, Lai CY, Zhang HQ, Ruan YZ, Zhao Y, Wang BB (2019) Effects of partial replacement of inorganic nitrogen by organic nitrogen on banana production and soil properties. Soil 51:879-887. https://doi.org/10.13758/j.cnki.tr.2019.05.006
- Wang YM, Lai CY, Zhang HQ, Ruan YZ, Zhao Y, Wang BB (2019) Organic nitrogen to replace part of inorganic nitrogen in banana production and the influence of soil properties. Soil 51(05):879-887. https://doi.org/10.13758/j.cnki.tr.2019.05.006
- Wang YY, Gao B, Zhang JL, Li XD (2014) Effects of different amounts of sulfur fertilizer on physiological characters, yield and quality of peanut. Shandong Agric Sci 46(12):67-71. https://doi.org/10.14083/j.issn.1001-4942.2014.12.018
- Wang ZF, Li YL, Guo WZ, Gao HB, Wang LC, Li LZ (2021) Effects of chelated calcium of EDTA on the growth and quality of lettuce cultivated without soil. Northern Hortic 477(06):53–58
- Wang ZH, Zhang XL, Zhang XH, Tang TX (2016) Effect of fertilization level on quality traits of sweet sorghum yield. China Sugars 38(04):36-38. https://doi.org/10.13570/j.cnki.scc.2016.04.011
- Warman P (1997) Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. Agric Ecosyst Environ 61:155–162. https://doi.org/10.1016/S0167-8809(96)01110-3
- Weber EA, Koller WD, Graeff S, Hermann W, Merkt N, Claupein W (2008) Impact of different nitrogen fertilizers and an additional sulfur supply on grain yield, quality, and the potential of acrylamide formation in winter wheat. J Plant Nutr Soil Sci 171:643– 655. https://doi.org/10.1002/jpln.200700229
- Wei GS, Hu CX, Tan QL, Zhu DH, Li XB (2018) Reducing nitrogen and phosphorus fertilization for the influence of the pomelo fruit yield and quality. J Plant Nutr Fert 24:471–478
- Wei JL, Cheng F, Cheng HC, Ning CH, Xu YS (1994) Effects of combined application of potassium and sulfur fertilizer on crop yield and quality. Chinese J Soil Sci 5:216-218. https://doi.org/ 10.19336/j.cnki.trtb.1994.05.009
- Wen M, Zhang J, Zheng Y, Yi S (2021) Effects of combined potassium and organic fertilizer application on newhall navel orange nutrient uptake, yield, and quality. Agron 11:1990. https://doi.org/10. 3390/agronomy11101990
- Wen MJ, Dang N, Zhai BN, Zheng W, Wang CH, Zhao ZY (2016) Fertilization with film sward dual cover effectively improve the yield and quality of apple of Weihe river. J Plant Nutr Fert 22(05):1339–1347
- Wen MJ, Dang N, Zhai BN, Zheng W, Wang ZH, Zhao ZY (2016) Fertilization combined with membrane raw grass binary mulching effectively improved the yield and quality of Weibei apples. Plant Nutr Fert Sci 22:1339–1347
- Wen PL, Tang M, Tong HD, Li DW, Zhao JH, Tong X (2018) Commodity organic fertilizer instead of testing the effect of fertilizer application in grapes. Shanghai Agric Sci Technol 370(04):104–105



- Weng XZ, Liu XM, Wang ZM (1995) Effect of navel spraying plant nutrient solution on its yield and quality. Fujian Fruit Tree 3:12–14
- Wood RM, Dunn BW, Waters DLE, Blanchard CL, Mawson AJ, Oli P (2020) Effect of agronomic management on rice grain quality Part III: Australian water saving irrigation practices. Cereal Chem 98:249–262. https://doi.org/10.1002/cche.10340
- Wu CF, Li HY, Liu Q, Liao MA, Liu L, Lv XL, Liang D, Wang J, Xia H, Lin LJ, Chen D, Tu MY (2021) Effects of exogenous melatonin on growth and fruit quality of peach. J Fruit Trees 38:40-49. https://doi.org/10.13925/j.cnki.gsxb.20200161
- Wu JH, Jiang JY, Li K, Su RF, Chen L (2012) Effects of spray application of microelement fertilizer on peanut yield and quality. J Henan Agric Sci 41(01):53-55. https://doi.org/10.15933/j.cnki. 1004-3268.2012.01.022
- Wu LY, Li ZZ, Ding W (2011) Study on application effect of slow and controlled release fertilizer on pomelo. Fujian Agric Sci Technol 4:77-78. https://doi.org/10.13651/j.cnki.fjnykj.2011. 04.048
- Wu MQ, Duan SR, Fan XP, Liu DB, Xia Y, Zhou JW, Kong XQ (2020) Effects of fulvic acid bio-organic fertilizer on the yield, quality and economic benefit of navel orange. Humic Acid 4:33-38. https://doi.org/10.19451/j.cnki.issn1671-9212.2020.04.004
- Wu MQ, Duan SR, Fan XP, Liu DB, Xia Y, Zhou JW, Kong XQ (2020) Effects of fulvic acid bio organic fertilizer on yield, quality and economic benefits of navel orange. Humic Acid 4:33-38. https:// doi.org/10.19451/j.cnki.issn1671-9212.2020.04.004
- Wu QM, Tian SH, Li YY, Pan YJ, Zhang Y (2021) Effects of microbial fertilizer on growth, yield and quality of cucumber. Biol Tech Bull 38:125-131. https://doi.org/10.13560/j.cnki.biotech.bull. 1985.2021-0432
- Wu XB, Peng FT, Cui XM, Xu YR, Sun YY, Zhang XD, Guo LF (2011) Effects of gun fertilization on nitrogen absorption and distribution, yield and quality of peach trees. J Plant Nutr Fert 17:680–687
- Wu XB, Peng FT, Cui XM, Xu YR, Sun YY, Zhang XD, Guo LF (2011) Fertilization gun fertilization on distribution of peach tree n uptake and production quality. J Plant Nutr Fert Peking Uni Core 17:680–687
- Wu YF (2014) Effects of biogas slurry application on yield and quality of navel orange. Beijing Agric 30:172–173
- Xi H, Li GL, Tao AA, Gu P, Han DD, Li N, Chen XJ (2021) Effect of drip application of organic liquid fertilizer on soil environment, fruit yield, quality and economic benefits of citrus cv. Beni madonna. Acta Agric Zhejiangensis 33(04):670–677
- Xi M, Xu YZ, Sun XY, Wu WG, Zhou YJ (2021) N earing fertilizer on rice chalk white grain grouting effect and relations with processing quality. China Agric Sci Technol Leader 23(09):144-151. https://doi.org/10.13304/j.nykjdb.2020.0118
- Xi RQ, Zhao XJ, Zhang KX, Wang YL, Ju XT (2010) Effects of different fertilization levels on yield, quality and nutrient balance of apples. Northwest Agric J 19:141–145
- Xia RQ, Song LY, He MZ (2016) Effects of different fertilization factors on sorghum grain starch. Seed World 399(02):29–32
- Xiang DB, Yang LL, Li J, Liu YN, Gao QL, Ren YK, Liu XY, Zhao G, Zhou Y, Huang HX, Zhang Y, Jia XF (2015) Effects of fertilization on buckwheat yield, economic benefit and fertilizer efficiency. Henan Agric Sci 44(04):83-87. https://doi.org/10. 15933/j.cnki.1004-3268.2015.04.018
- Xiao Q, Zhang FD, Wang YJ, Zhang JF, Zhang SQ (2008) Nanometer material cementation type coated slow/controlled release fertilizer effect on crop yield and quality. J Plant Nutr Fert 5:951–955
- Xiao RY, Li YS, Cao SP, Lian ZW (2019) Effects of fertilization on yield and quality of *Brassica napus* in rice tanker farming area in southern Henan. Soil Fert Sci China 5:79–84

- Xiao YB, Wan QY, Ge X (2012) Effect of nitrogen on the yield and quality of banana under fertigation. Chinese J Trop Crops 33(01):55–58
- Xiao YR (2019) Effects of nitrogen application rate on yield and quality of high-quality wheat in sandy ginger black soil area. Bull Agric Sci Technol 6:91–92
- Xie J, Zhao YN, Chen XJ, Li DP, Xu CL, Wang K, Zhang YQ, Shi XJ (2016) Organic nitrogen instead of fertilizer nitrogen increase maize yield and N uptake efficiency. China Agric Sci 49(20):3934–3943
- Xie KZ, Xu PZ, Yang SH, Zhang FB, Tang SH, Chen JS, Huang X, Gu WJ (2010) Study on benefit evaluation of resource-saving fertilization model for citrus orchards on dry and sloping land based on organic and inorganic combined application. Chinese Agric Sci Bull 26(23):214–218
- Xie RC, Huang LN, Lei F, Zhang DM, Cheng SM, Zhao ZX, Wei SX (2021) Effects of fertilizer reduction combined with bio-organic fertilizer on yield and quality of banana. South China Fruits 50:58-62. https://doi.org/10.13938/j.issn.1007-1431.20200859
- Xie TY, Liu FX, Li YE, Lei T, Luo GH (2008) Hangzhou night sweet pomelos formula fertilization experiment. Fujian Fruit Trees 1:14–15
- Xing PF, Gao SC, Ma MC, Zhou XL, Zhao TK, Sun JD, Shen DL (2016) Replacing part of the inorganic fertilizer on farmland soil physical and chemical properties, enzyme activity of north China and the influence of crop yield. Soil Fert China 263(03):98–104
- Xu CK, Chen PF, Sun H, Zhang JD, Huang M (2011) Effect of nitrogen application rate on yield and quality of 'Suyou No. 4' rapeseed. J Shanghai Agric 27(03):47-50.
- Xu CK, Cheng PF, Sun H, Zhang JD, Huan M (2011) Effects of nitrogen application rate on yield and quality of Suyou 4 rape. Acta Agric Shanghai 27:47–50
- Xu E, Wang DY, Li JZ (1982) Study on physiological fruiting control of Washington navel orange by 6-benzylamine purine and gibberellin. Acta Hortic Sinica 2:5–12
- Xu GY, Yu HL, Xu BB, Lu ZH, Wang ZQ, Wang LR, Si P (2022) Effects of local fertilization on peach growth, fruit quality and yield. China's Fruit Trees 2:38-42. https://doi.org/10.16626/j. cnki.issn1000-8047.2022.02.007
- Xu PZ, Chen JS, Li HB, Zhang FB, Tang SH, Huang X (2007) Effects of applying green food specific organic fertilizer on yield and quality of banana. China Agric Sci Bull 5:421–424
- Xu PZ, Yang SH, Xie KZ, Chen JS, Zhang FB, Tang SH, Huang X (2008) Study on the effect of organic and inorganic fertilizer combined application in sloping citrus orchard of Guangdong Province. Guangdong Agric Sci 220(07):65-67. https://doi.org/ 10.16768/j.issn.1004-874x.2008.07.044
- Xu XW, Fan JB, Chen Y, Zhang QH, He YQ, Zheng BX (2015) Effects of combined application of organic and inorganic fertilizers on physiological characteristics yield and quality of peanut in red soil dryland. J Soil 52(01):174–182
- Xu Y, Gu D, Li K, Zhang W, Zhang H, Wang Z, Yang J (2019) Response of grain quality to alternate wetting and moderate soil drying irrigation in rice. Crop Sci 59:1261. https://doi.org/10. 2135/cropsci2018.11.0700
- Xue L, Yu Y, Yang L (2014) Maintaining yields and reducing nitrogen loss in rice-wheat rotation system in Taihu Lake region with proper fertilizer management. Environ Res Lett 9:115010. https:// doi.org/10.1088/1748-9326/9/11/115010
- Yadav SK, Khokhar UU, Sharma SD, Kumar P (2015) Response of strawberry to organic versus inorganic fertilizers. J Plant Nutr 39:194–203. https://doi.org/10.1080/01904167.2015.1109115
- Yan GW, Xing MZ, Chai TH, Wang SP (2021) New the influence of soil conditioner on cucumber yield and quality. Hebei Agric 9:59–61



- Yan K, Jiang YL, Tang JY, Dai QG (2018) N application and under the condition of saline-alkali ZaiCha density effects on rice yield and quality. Soil Fert China 2:67–74
- Yan SJ, Tian RX, Chai WC, Liu J, Zhang JN (2021) Straw mulching on winter crop of eggplant growth and development, quality and soil environment. Northeast Agric Sci 46:76-81. https://doi.org/ 10.16423/j.cnki.1003-8701.2021.05.017
- Yang B, Xiong Z, Wang J, Xu X, Huang Q, Shen Q (2015) Mitigating net global warming potential and greenhouse gas intensities by substituting chemical nitrogen fertilizers with organic fertilization strategies in rice-wheat annual rotation systems in China: a 3-year field experiment. Ecol Eng 81:289–297. https://doi. org/10.1016/j.ecoleng.2015.04.071
- Yang BM, Li JQ, Yao LX, Li GL, He ZH, Zhou CM, Tu SH (2010) Effect of potassium, calcium and magnesium on yield, quality, and storage property of banana. Chinese J Eco Agric 18(02):290–294
- Yang CX, Ni DW, Chen XY, Qu J (1993) Effects of titanium fertilizer on yield and quality of crops such as rice, rapeseed and watermelon. Zhejiang Agric Sci 1:41–42
- Yang J (2013) Spraying trace elements on winter wheat and summer maize growth and development, production and quality. Huazhong Agric Uni.
- Yang LL, Lu KZ, Qi GH, Zhang XM, Li H, Guo SP (2020) Optimum application amount and times of calcium nitrate for better fruit quality and lower incidence of apple bitter pit. Plant Nutr Fert Sci 26:765–772
- Yang R, Liang X, Torrion J, Walsh O, O'Brien K, Liu Q (2018) The influence of water and nitrogen availability on the expression of end-use quality parameters of spring wheat. Agron 8:257. https://doi.org/10.3390/agronomy8110257
- Yang WX, Wang P, Yang XY, Li J (2010) Effects of foliar selenium application on yield and quality of rape. J Inner Mongolia Agric Uni 31:88–90
- Yang WX, Wang P, Yang XY, Li J (2010) Foliar application of selenium effects on rape yield and quality. Inner Mongolia Agric Uni 31(03):88–90
- Yang XS, Zhao HJ (2021) Different substrates on the cucumber growth, yield and fruit quality. Vegetables 11:11–15
- Yang Y, Qiu X (2017) Response of growth, yield and quality of "Shuguang" nectarine to nitrogen application level. Northern Hortic 23:58–63
- Yang YC, Zhang M, Zheng L, Cheng DD, Liu M, Geng YQ (2011) Controlled release urea improved nitrogen use efficiency, yield, and quality of wheat. Agron J 103:479. https://doi.org/ 10.1016/j.fcr.2015.07.009
- Yang Z, Xiao SY, Chen SY, Liu J, Zhu WJ, Xu X, Li L, Guo F, Lan SL (2021) Effects of nitrogen application rate on yield and quality of large flower with different oleic acid content. J Henan Agric Sci 50:44-52. https://doi.org/10.15933/j.cnki. 1004-3268.2021.09.006
- Yang ZZ, Chi FQ, Kuang EJ, Zhang JM, Su QR, Zhang YW, Liu YD (2019) Organic fertilizer instead of comprehensive evaluation of soil physical and chemical properties and yield. North China Agric Peking Uni Core 34(S1):153–160
- Yao LX, Zhou XC, Cai YF (2004) A study on the appropriate application ratio of nitrogen and potassium fertilizers in banana. Guangdong Agric Sci 1:35-36. https://doi.org/10.16768/j.issn. 1004-874x.2004.01.013
- Yasir R, Hafeez MB, Khan S, Nadeem M, S, Rahman, S, Batool, J, Ahmad (2020) Biofortifcation with zinc and iron improves the grain quality and yield of wheat crop. Int J Plant Prod 14:501–510. https://doi.org/10.1007/s42106-020-00100-w
- Ye MH (2020) Effects of different fertilization treatments on yield and quality of pitaya fruit. J Guangxi Agric 35(01):32–35

- Ye JW (2021) Guanxi Sanhong pomelo application of different organic fertilizer effect comparison summary. Fujian Trop Sci Technol 46:23–24
- Yener H, Altuntaş Ö (2020) Effects of potassium fertilization on leaf nutrient content and quality attributes of sweet cherry fruits (*Prunus Avium* L.). J Plant Nutr 44:946–957. https://doi.org/ 10.1080/01904167.2020.1862203
- Yoldas F, Ceylan S, Yagmur B, Mordogan N (2008) Effects of nitrogen fertilizer on yield quality and nutrient content in broccoli. J Plant Nutr 31:1333–1343. https://doi.org/10.1080/0190416080 2135118
- Youssef MA, Arwa AAH, Esmat FA, Ali M (2021) Organic amendment and mulching enhanced the growth and fruit quality of squash plants (*Cucurbita pepo* L.) grown on silty loam soils. Hortic 7:269. https://doi.org/10.3390/horticulturae7090269
- Yu C, Dong ZX, Zhu ZX, Li Y, Mo RL, Deng W, Xiong C, Hu XM (2020) Different fertilizer treatments on fruit mulberry leaf photosynthesis and fruit quality and the influence of the soil microbial number. Acta Sericologica Sinica 46(01):19-25. https://doi. org/10.13441/j.cnki.cykx.2020.01.003
- Yu GJ, Wang SZ, Dong ZH, Li LL, Wang HH (2021) Lettuce foliar spraying of organic water-soluble fertilizer-peptide harvestTM experiment. Tianjin Agric Forestry Technol 21:16-17. https:// doi.org/10.16013/j.cnki.1002-0659.2021.0063
- Yu HL, Si P, Shao W, Yang XJ, Qiao XS, Du XH (2018) Application effect of different iron fertilizer on 'chunmi' peach. China Fruits 5:30-32. https://doi.org/10.16626/j.cnki.issn1000-8047.2018.05.008
- Yu HL, Xu BB, Xu GY, Shao W, Liu HM, Zhang ZH, Qiao XS, Si P (2021) Optimum application of seaweed extracts promote the yield, quality and nutrient absorption of peach fruit. Plant Nutr Fert Sci 27:1656–1664
- Yu Q, Zhang X, Suo YY, Si XZ, Li L, Qiu LJ, Cheng PJ, Yu H (2020) Effects of selenium application on selenium distribution, yield and quality of different genotypes of peanut. J Peanut Sci 49:57-62. https://doi.org/10.14001/j.issn.1002-4093.2020.04.009
- Yuan Q, Feng B, Zhong YH, Wang J, Xu XJ, Wang HB (2021) Organic fertilizer instead of chemical fertilizer on eggplant yield, quality and the effect of soil fertility. China Agric Notif 37:59–63
- Yuan QL, Lv GJ, Liu XG (2022) Fertilizer treatment on chili agronomic traits, yield and quality. Water Sav Irrig 3:45–49
- Yuan WL, Liu ZX, Wu JP, Yin HQ, Chen LF (2020) Effects of selenium on lettuce growth, quality, nutrient absorption and selenium conversion. North China J Agric Sci 35(S1):189–194
- Yue T, Mao XH, Cheng LL, Feng XH (2021) Small molecule organic water-soluble fertilizer influence on yield and quality of tomato and cucumber. Zhejiang Agric Sci 62:330-333. https://doi.org/ 10.16178/j.issn.0528-9017.20210228
- Yue YK, Jin CY, Zhang M, Li ZY (2021) Effects of different nitrogen and calcium levels on fruit quality of sheltered peach. China's Fruit Trees 4:55-58. https://doi.org/10.16626/j.cnki.issn1000-8047.2021.04.011
- Zegbe JA, Serna-Pérez A, Mena-Covarrubias J (2015) Soil applications of NPK affect fruit quality and shelf-life of 'Cristalina' cactus pear. Fruits 70:297–302. https://doi.org/10.1051/fruits/2015024
- Zeng DF, Wang SQ, Fang GQ (1965) A preliminary experiment of using grass and wood ash for extra-root topdressing during the flowering period of rice. Tillage Fert 3:30–32
- Zeng RQ, Cai JX (2021) The influence of chitin fertilizer on grain yield and quality of sweet pomelos. Southeast Gardening 9:31–33
- Zeng WG, Liu YP (1991) Study on the effect of plastic film mulching on citrus I. effect on yield and quality. J Sichuan Agric Uni 1:34–40
- Zeng Z, Wu XL, Zhuo MH, Zeng QC (2014) Preliminary report on formula fertilization test of red pomelo. Agric Technol 34:20–22
- Zhang B, Cakmak I, Feng J, Yu C, Chen X, Xie D, Wu L, Song Z, Cao J, He Y (2020) Magnesium deficiency reduced the yield and



seed germination in wax gourd by affecting the carbohydrate translocation. Front Plant Sci 11:797. https://doi.org/10.3389/fpls.2020.00797

- Zhang C, Zhang H, Zhou X, Zhai H, Yan JF (2017) Apple specific fertilizer on orchard soil physical and chemical properties and production, the influence of the quality. Soil Fert China 270(04):24–30
- Zhang C, Zhang H, Zhou X, Zhai H, Yan JF (2017) Effects of apple fertilizer on soil physicochemical properties and apple yield and quality in orchard. Soil Fert China 4:24–30
- Zhang F, Mackenzie AF, Smith DL (1993) Corn yield and shifts among corn quality constituents following application of different nitrogen fertilizer sources at several times during corn development. J Plant Nutr 16:1317–1337. https://doi.org/10.1080/0190416930 9364615
- Zhang GC, Li JX (1998) Effect of PBO on improving yield and quality of navel orange root. Guangxi Citrus 1:12–13
- Zhang GL, Chen T, Yu HL, Yin WN, Ma GJ (2021) Effects of fertilizer reduction and organic substitution on eggplant growth and soil nutrients. North Garden 14:46–50
- Zhang H, Zhu DJ, Huang H, Ning YW, Zhang YC (2012) Effects of different fertilization treatments on yield and quality of rape. Soil 44:966-971. https://doi.org/10.13758/j.cnki.tr.2012.06.023
- Zhang H, Zhu DJ, Huang H, Ning YW, Zhang YC (2012) The influence of different fertilizer treatment on rapeseed yield and quality. Soil 44(06):966-971. https://doi.org/10.13758/j.cnki.tr.2012.06.023
- Zhang HH, Wang YF, Zhang XJ, Wang ML, Zhao CX (2016) Effects of controlled release fertilizer on soil nutrient content and yield and quality in peanut field. J Peanut Sci 45(02):27-32. https://doi. org/10.14001/j.issn.1002-4093.2016.02.005
- Zhang J, Li B, Zhang J, Christie P, Li X, Bhat SA (2020) Organic fertilizer application and Mg fertilizer promote banana yield and quality in an Udic Ferralsol. PLoS One 15:e0230593. https://doi. org/10.1371/journal.pone.0230593
- Zhang J, Li JJ, Wan LJ, Yang JB, Zheng YQ, Lv Q, Xie RJ, Ma YY, Deng L, Yi SL (2020) Effects of potassium application on nutrients, yield and quality of newhall navel orange. Chinese Agric Sci 53:4271–4286
- Zhang J, Li JJ, Yang JB, Zheng YQ, Lv Q, Xie RJ, Ma YY, Deng L, Yi SL (2020) Effects of potassium application levels on nutrient, yield and quality of newhall navel orange. Agric Sci China 53:4271–4286
- Zhang JD, Wang JT, Kong X, Wang J, Tang J, Wu DF, Li LL, Yue YP (2020) Effects of different fertilizer applications on lettuce growth, development and yield quality. J Sci Technol Henan Uni Sci Technol 48(03):10–14
- Zhang JX, Wang FR, Yang ZQ, Lei JM, E, Sz, YH, Wang (2019) Response of production quality and soil quality of *Brassica napus* to different fertilizer combinations in Huangmian soil area. Acta Agric Boreali-occidentalis Sinica 28:1821–1829
- Zhang JX, Wang FR, Yang ZQ, Lei JM, E SZ, Wang YH (2019) Yellow spongy soils area winter variety of *B. Napus* rape production quality and the response of the soil quality of different preparation. J Northwest Agric 28(11):1821-1829.
- Zhang L, Du XM (2013) Effects of combined application of nitrogen and potassium fertilizer on yield and quality of vegetable rape. Northern Hortic 24:176–178
- Zhang L, Li P, Wang WR, Wu WQ, Wang YP, Wang YP (2021) Salt stress are mild soil conditioner cucumber soil fertility and the influence of the growth and development of the facilities. North Garden 9:50–60
- Zhang LX, Geng ZC, Zhang CY, Zhao RL (2004) Application patterns of organic fertilizer under different water conditions in red fuji apple orchard in Weibei dry plain. J Northwest Forestry College 4:68–71

- Zhang MQ, Li J, Kong QB, Yao BQ, Ding W (2015) Suitable amount of nitrogen and potassium fertilizer for banana in Zhangzhou and its effect on quality. Chinese J Trop Crops 36(02):263–268
- Zhang N, Cheng YX, Zhang P, Wang JJ, Lei JW, Gao J (2021) Effects of nitrogen reduction and amino acid fertilizer replacement on growth, yield and quality of dried pepper. Chinese Veg 34:89-93. https://doi.org/10.16861/j.cnki.zggc.2021.0297
- Zhang R, Wang YX, Zhao XH, Li L, Fu XL, Gao DS (2016) Seaweed manure on soil fertility and applying different content 'feicheng peach quality. J Plant Physiol 52:1819-1828. https://doi.org/10. 13592/j.cnki.ppj.2016.0030
- Zhang SR, Sun XB (2015) Effects of different fertilization rates on yield quality of sweet sorghum for alcohol and feed. Chinese Sugars 37(02):41-42. https://doi.org/10.13570/j.cnki.scc.2015. 02.015
- Zhang SY, Lei YH, Li SL, Shen T (2019) With rotten cow dung for organic components on lettuce growth and quality of the different ratio of matrix impact study. China Biogas 37(01):98–103
- Zhang X, Mao JW, Si ZX, Li GP (2014) Effects of different kinds of organic fertilizer combined with molybdenum fertilizer on growth, yield and quality of continuous cropping peanut. Chinese J Oil Crop Sci 36(04):489–493
- Zhang XG (2014) Jin Qiuli orchard organic inorganic fertilizer effect research. Guangdong Agric Sci 41(08):87-91. https://doi.org/ 10.16768/j.issn.1004-874x.2014.08.036
- Zhang XH, Zhang XJ, Hou R, Zhang XQ, Yue FL, Xu MY, Cai CW, Liu CQ, Li WJ (2015) Application effect of liquid selenium fertilizer on black peanut cultivation. J Peanut Sci 44(03):47-50. https://doi.org/10.14001/j.issn.1002-4093.2015.03.008
- Zhang XM, Sun YX, Wang WJ, Yuan MM, Wu G, Hu P, Yang YB (2018) Organic fertilizer partly replaces characteristics and nitrogen fertilizer on rice soil for nitrogen apparent effects of profit and loss. J Agron 8(12):28–34
- Zhang XW, Mao T, Zhao R, Liu JR, Qin JH (2021) Selection of ecological fertilizer formula of livestock manure and its effect on soil physical and chemical properties, enzyme activities and cucumber quality in greenhouse. Dry Areas Agric Res 39:119–127
- Zhang XX, Han XR, Huang YQ, Yang JF, Wang Y, Jiang Z (2012) Effects of fertilization on plant trait, yield and quality of peanut under continuous cropping. J Shenyang Agric Uni 42(05):610–613
- Zhang Y, Hu C, Tan Q et al (2015) Soil application of boron and zinc influence fruit yield and quality of satsuma mandarin in acidic soils. Agron J 107:1–8. https://doi.org/10.2134/agronj14.0122
- Zhang Y, Hu CX, Tan QL, Nie ZJ, Zheng CS, Gui HP, Sun XC, Zhao XH (2015) Soil application of boron and zinc influence fruit yield and quality of satsuma mandarin in acidic soils. Agron J. https://doi.org/10.2134/agronj14.0122
- Zhang Y, Yan Y, Fu C, Li M, Wang Y (2016) Zinc sulfate spray increases activity of carbohydrate metabolic enzymes and regulates endogenous hormone levels in apple fruit. Sci Hortic 211:363–368. https://doi.org/10.1016/j.scienta.2016.09.02
- Zhang YF, Luo JJ, Peng FT, Gao HF, Wang GD, Sun XW (2017) Effects of fertilizer being bag-controlled released on root growth, nitrogen absorption and utilization, fruit yield and quality of peach trees. Agric Sci China 50:4769–4778
- Zhang YF, Peng FT, Xiao YS, Luo JJ, Du AQ (2020) Effects of potassium fertilizers being bag-controlled released on fruit yield and quality of peach trees and soil chloride content. Agric Sci China 53:4035–4044
- Zhang YP, Chen GF, Yin H, Tang QZ, Li XF (2013) Reduced fertilization and organic-inorganic combined application effect on sugarcane. Guangxi Agric Rep 28(05):9–11
- Zhang YP, Fan HW, Yang SJ, Xu S, Chen YY (2014) Organic-inorganic compound fertilizer with impact on muskmelon plant growth, yield and quality. J Shanghai Agric 30(05):11–15



- Zhang GL et al (1998) Rice application plant power 2003 effect. Henan Science and Technology 9:1
- Zhao HC, Li HY, Chen LQ, He C, Zhen GP, Han X, Han X, He WC, Zhou YF (2018) Silicon nitrogen with cold on the rice production product quality and resistance to pour. J Shanghai Agric 34(04):36-42. https://doi.org/10.15955/j.issn1000-3924.2018.04.08
- Zhao HT, Li TP, Zhang Y, Hu J, Bai YC, Shan YH, Ke F (2017) Effects of vermicompost amendment as a basal fertilizer on soil properties and cucumber yield and quality under continuous cropping conditions in a greenhouse. J Soils Sediments 17:2718–2730. https://doi.org/10.1007/s11368-017-1744-y
- Zhao LL, Li YJ, Ci ZJ, Sha YF, Zhang RQ, Liu MY, Jiang ZW (2014) Effects of rice husk carbon fertilizer on body growth and fruit quality of Fuji apple tree. Yantai Fruit Trees 1:17–18
- Zhao TH, Zhang ZM, Feng HZ (1990) Effects of zinc manganese fertilizer on yield and quality of dryland rice. J Agric Uni Hebei 3:118–120
- Zhao Y, Huang N, Liu JP, Zhou J, Li S, Li Y (2019) Optimized fertilization in Beijing suburbs area facilities lettuce yield, quality and the influence of soil available nutrients. Chinese Veg 32(09):42-44. https://doi.org/10.16861/j.cnki.zggc.2019.0230
- Zhao Y, Luo JH, Chen XQ, Zhang XJ, Zhang WL (2012) Greenhouse tomato-cucumber yield and soil N leaching as affected by reducing N rate and adding manure: a case study in the Yellow River Irrigation Region China. Nutr Cycl Agroecosystems 94:221–235. https://doi.org/10.1007/s10705-012-9535-8
- Zhao YF, Mu LH, Chang KQ, Du YP, Chen Y, Ma CB (2010) Effects of precise fertilization of different cultivation densities and N, P, K ratios on buckwheat yield. Inner Mongolia Agric Sci Technol 4:61–62
- Zhao ZO, Tong YA, Liu F, Wang XY (2013) Effects of long-term fertilization treatment on apple yield, quality and soil fertility. Chinese J Appl Ecol 24:3091-3098. https://doi.org/10.13287/j. 1001-9332.2013.0532
- Zhao ZP, Gao YM, Liu F, Wang XY, Tong YA (2013) Organic fertilizer with chemical fertilizer applied to apple leaf nutrient, the influence of the quality and yield. J Hortic 40(11):2229-2236. https:// doi.org/10.16420/j.issn.0513-353x.2013.11.018
- Zhao ZP, Tong YA (2016) Different fertilizer treatment on grain yield and quality of fuji apple and the influence of water resistance. J China Agric Uni 21(04):26–34
- Zhao ZP, Tong YA, Liu F, Wang XY (2013) Long-term different fertilizer treatments on apple production, quality and the effect of soil fertility. J Appl Ecol 24(11):3091-3098. https://doi.org/10. 13287/j.1001-9332.2013.0532
- Zheng GD, Huang JT, Chen HL, Li SP, Xie ZQ (2013) Effects of foliar spraying of boron and molybdenum fertilizer on yield and quality of peanut. Fujian Agric Sci Technol 279(11):52-54. https://doi. org/10.13651/j.cnki.fjnykj.2013.11.028
- Zheng SY, Zhao HT, Wu FY, Zhao LM, Li TP, Qian RY, Shan YH, Feng K (2018) Effects of vermicompost replacing part of inorganic base fertilizer on cucumber growth and soil properties in greenhouse continuous cropping. Shanghai J Agric Sci 34:1-7. https://doi.org/10.15955/j.issn1000-3924.2018.05.01
- Zheng XY, Zhao CB, Zhi ZP, Sun ZP (2020) Fertilizer reduction of sunlight greenhouse cucumber growth and soil fertility. J Jiangxi Agric Uni 42:1151-1158. https://doi.org/10.13836/j.jjau.2020128
- Zheng YP, Wu LR, Wu ZF, Wang CB (2011) Effects of different fertilization treatments on peanut yield, quality and senescence. Crops 141(02):45-48. https://doi.org/10.16035/j.issn.1001-7283.2011. 02.013
- Zhong H, Huang M, Wu DH, Luo H (2016) Effects of different fertilization times on yield and quality of navel orange in high yield period. Grass Roots Agric Technol Ext 4:47–49
- Zhou CL (1993) Effects of different fertilization levels and planting densities on green tree yield. Agric Sci Technol Tibet 2:19–22

- Zhou HP, Hao BP, Guan CL, Xie WY (2009) Effects of fertilization on growth and nutritional quality of forage sorghum. Chinese J Eco Agric 17(01):60–63
- Zhou LB, Wang C, Lu XJ, Zhang GB, Xu Y, Wu LY, Shao MB (2016) Effects of fertilization amount and planting density on photosynthetic characteristics, agronomic traits and yield of glutinous sorghum Qiangao No. 7. Southern J Agric Sci 47(05):644-648.
- Zhou LY, Li XD, Wang LL, Tang X, Lin YJ (2008) Effects of different Ca applications on physiological characteristics, yield and quality in peanut. Acta Agro Sinica 5:879–885
- Zhou LY, Li XD, Tang X, Lin YJ, Li ZF, Li BL (2007) Effects of N, P, K fertilizer combined application on physiological characteristics, yield and kernel quality of peanut. Acta Ecol Sinica 6:2707–2714
- Zhou M, Zhu B, Brüggemann N, Bergmann J, Wang Y, Butterbach-Bahl K (2013)  $N_2O$  and  $CH_4$  Emissions, and  $NO_3^-$  leaching on a crop-yield basis from a subtropical rain-fed wheat-maize rotation in response to different types of nitrogen fertilizer. Ecosystems 17:286–301. https://doi.org/10.1007/s10021-013-9723-7
- Zhou M, Zhu B, Brüggemann N, Dannenmann M, Wang Y, Butterbach-Bahl K (2016) Sustaining crop productivity while reducing environmental nitrogen losses in the subtropical wheat-maize cropping systems: a comprehensive case study of nitrogen cycling and balance. Agric Ecosyst Environ 231:1–14. https://doi.org/ 10.1016/j.agee.2016.06.022
- Zhou RR, Chen P, Guo SR, Cai Z (2021) Vinegar bad matrix modifier and mushroom slag soil physical and chemical properties of continuous cropping obstacle and the influence of the cultivation of cucumber. Chinese Veg 3:57-64. https://doi.org/10.19928/j. cnki.1000-6346.2021.1005
- Zhou X, Xu NL, Zhou NN, Xu MB, Wang S (2021). Reduction of nitrogen application under the condition of vermis manure on soil properties and the influence of the rice yield and quality. Barley Grain Sci 38(03):44-48. https://doi.org/10.14069/j.cnki. 32-1769/s.2021.03.009
- Zhu GQ (2017) Meat of organic fertilizers on the fruit quality and yield, and because the impact analysis. China Agric Info 13:46–48
- Zhu K, Song C, Liu J, Gong M, Wang S, Song X, Li J (2021) Unravelling the mechanisms of improving wheat growth, yield, and grain quality under long-term corn straw return plus N fertilizer mode. J Soil Sci Plant Nutr 21:3428–3436. https://doi.org/10. 1007/s42729-021-00617-7
- Zhu Q, Ozores-Hampton M, Li Y, Morgan K, Liu G, Mylavarapu RS (2017) Responses of tomato to potassium rates in a calcareous soil. HortScience 52:764-769. https://doi.org/10.21273/HORTS CI11753-17
- Zhu XY, Feng HP, Solang OZ, Wang GX, Xiao ZX, Feng ZR, Min ZP, Tang WD (1991) Study on the ratio of nitrogen, phosphorus and fertilizer combinations in spring green trees. Agric Studies Arid Areas 1:17–23
- Zhu YB, Chen ZB (1989) The influence of potassium chloride on grain yield and quality of tomato. Gansu Agric Sci Technol 2:20–21
- Zhu ZL (2019) Effect of citrus-specific BB fertilizer on Newhall navel oranges. Southeast Hortic 3:7–10
- Zuo Y, Zhang J, Zhao R, Dai H, Zhang Z (2018) Application of vermicompost improves strawberry growth and quality through increased photosynthesis rate, free radical scavenging and soil enzymatic activity. Sci Hortic 233:132–140. https://doi.org/10. 1016/j.scienta.2018.01.023

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

