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Optimal Effect of Substituting Organic Fertilizer for Inorganic Nitrogen on Yield and Quality of Winter Wheat under Drip Irrigation

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Abstract: More than one-third of the global population relies on wheat as a staple food. To ultimately reduce inorganic nitrogen (N) usage through applying an organic fertilizer under drip irrigation and evaluate its effect on the yield, quality, and N utilization efficiency of winter wheat (variety Jimai 22) under various irrigation systems, an experiment was established and conducted in Yanghe Town, Jiaozhou City, from October 2020 to June 2022. The trial was designed with seven treatments, including a control (CK), to achieve a 25% total nitrogen reduction in all treatments except for CK. These treatments included drip irrigation with urea as CK, one-time application of urea through drip irrigation (FU1), one-time application of organic water-soluble fertilizer through furrow irrigation (FO1), one-time application of organic water-soluble fertilizer through drip irrigation (DO1), two-time application of organic water-soluble fertilizer through drip irrigation (DO2), one-time application of urea through drip irrigation (DU1), and two-time application of urea through drip irrigation (DU2). The results indicated that the application of a reduced N fertilizer plus an organic fertilizer significantly improved the dry matter accumulation (DMA) and the efficiency of N absorption and thus increased the grain yield. The DO2 treatment significantly exhibited a 15.5% and 16.9% increase in the DMA and the grain DMA in post-anthesis, respectively, compared to those of CK in the season of 2020–2021. Overall, the apparent nitrogen use efficiency with the drip irrigation topdressing treatments (DO1, DO2, DU1, DU2) increased significantly over two years in comparison with the urea fertilization through traditional furrow irrigation (CK), while the DO2 and DU2 treatments improved most significantly in the N use efficiency and N agronomic efficiency. Therefore, a reduced use of the inorganic N fertilizer with some organic fertilizers significantly increased the weight of thousand-grains and the yield of winter wheat, especially in the DO2 treatment, with an 11.7 t/ha and 10.9 t/ha increase, respectively, in both growing seasons of two years, while the DO2 treatment also improved the extensibility of wheat flour dough from grains harvested in both rainy (2020–2021) and less rainy (2021–2022) growing seasons. Therefore, we strongly recommend that two-time application of an organic water-soluble fertilizer through drip irrigation be the option to reduce the use of inorganic N fertilizers and increase the yield and quality of winter wheat under the conditions of this experiment.

Keywords: reduction of inorganic nitrogen fertilizer; substitution with bio-organic nitrogen fertilizer; drip irrigation; winter wheat

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1. Introduction

Wheat is one of the important grain crops in China, and eco-friendly cultivation for the high yield and quality of wheat grains has been of great significance to secure Chinese food supply and improve the quality of the national diet [1]. Wheat serves as the primary source of flour and flour-based products in the diet. Additionally, while it is suitable for bread baking, this process demands specific quality standards for the wheat used. Consequently, ensuring both the high yield and superior quality of wheat remains a pressing challenge in wheat production [2,3]. In recent years, the use of inorganic fertilizers has been intensified carelessly year by year solely for a high yield to an extent that has caused ecological pollution, a reduction in the efficiency of fertilizer utilization, and subsequently, a decline in the crop's economic value [4]. Therefore, a reasonable, alternative, and optimized approach to minimize the use of inorganic fertilizers is an important way for the green production of wheat.

Nitrogen (N) is an essential nutrient element that promotes the growth and development of plants including wheat and plays a critical role in its yield and quality. However, more N does not always promote the growth or produce more grains as expected [5]. A high N content increases the wheat grain glutenin and storage proteins and so improves grain quality [6,7]. However, over-applied N can prolong wheat fertility, increase seed filling time, and reduce grain weight, which can be detrimental to the wheat yield increase [8]. An optimized irrigation schedule and judicious nitrogen application significantly enhances the dry matter accumulation (DMA) and grain yield of wheat [9]. Using the micro-sprinkler irrigation equipment with an application rate of 210 kg/ha N at a 5:5 ratio of base to follow-up fertilization has proven to be more conducive to improving the efficiency of water and N utilization, promoting carbon (C) and N metabolisms, and increasing the wheat yield [10]. Liu et al. [11] demonstrated that excessive N fertilizer application inhibits grain filling during wheat growth, leading to a reduction in grain yield. Fan et al. [12] demonstrated that under night warming conditions, a N application rate of 240 kg/ha was beneficial for the accumulation and transport of dry matter in wheat, leading to an increase in grain yield. Li et al. [13] showed that in the eastern irrigation area of the Loess Plateau, when the nitrogen application rate was 187~276 kg/ha, it was beneficial to increase the dry matter accumulation of wheat, improve NUE, and achieve high yield and high efficiency. In Northwest China, using drip irrigation equipment in mildly water-deficit areas is beneficial for winter wheat in the post-flowering period to accumulate and transport dry matters for more yields with medium fertilization [14].

Organic fertilizers are used to increase the content of organic matter in soil and mitigate nutrient losses. With the use of inorganic fertilizers, organic ones can enhance the N utilization rate, increase crop yields, and protect the land environment from being polluted [15]. Ma et al. [16] conducted a study using ^{15}N-labeled organic fertilizer, which demonstrated that the combined application of organic and inorganic fertilizers was beneficial for N absorption in wheat, leading to increased wheat yield and nitrogen use efficiency. The application of microbial organic fertilizer improved soil nutrient content, enhanced the effective utilization of N fertilizer, and further increased wheat yield in the North China Plain [17]. Zhou et al. [18] concluded that the combination of inorganic and organic fertilizers improved the content of soil organic matter and increased the wheat yield in a long-term field trial. In another study, with an equal amount of N, organic fertilizer was applied to replace a portion of inorganic fertilizer, through which the soil nutrient status and wheat roots were significantly improved, and the grain yield increased, and the efficiency of N utilization were enhanced [19]. Through a meta-analysis, the application of organic fertilizers was also proven to improve the NUE and water use efficiency for increased wheat yield and improved soil condition [20].

All evidence derived from the reports mentioned above have strongly indicated the effectiveness of using organic fertilizers to reduce N sources from the inorganic fertilizers, and this has been more and more recognized; however, few studies with similar research have been conducted on winter wheat under drip irrigation. Therefore, an experiment was designed and carried out to assess the effect of the inorganic N reduction through using organic fertilizer application on the N utilization efficiency, yield, and quality of winter wheat under drip irrigation, which may shed some light on how to grow winter wheat more productively and economically and in a more eco-friendly manner at a large scale.

2. Materials and Methods

2.1. Experimental Site and Design

The experiment was conducted from October 2020 to June 2022 in Yanghe Town, Jiaozhou City (119°37′ E, 36°15′ N), with an average annual temperature of 12.5 °C and an average annual precipitation of 673.6 mm. The soil is identified as brown fluvo-aquic with a pH of 5.3. Its base nutrient composition includes 13.4 g/kg of organic matter, 1.2 g/kg of total nitrogen, 97.2 mg/kg of alkaline-dissolved nitrogen, 32.4 mg/kg of readily available phosphorus, and 154.2 mg/kg of readily available potassium.

Wheat variety of Jimai 22 was used for the trial, and seven fertilization treatments (Table 1) included the following: (1) the traditional sprinkler irrigation with urea follow-up fertilizer to maintain 25% more N than all other treatments as the control (CK), (2) one application of urea application through sprinkler irrigation (FU1), (3) one application of follow-up organic water-soluble fertilizer through furrow irrigation (FO1), (4) one application of follow-up organic water-soluble fertilizer through drip irrigation (DO1), (5) two applications of follow-up organic water-soluble fertilizer through drip irrigation (DO2), (6) one application of follow-up urea (DU1) plus two applications of follow-up urea (DU2) through drip irrigation, of which FO1, DO1, DO2 had 16.7% and 16% of the base fertilizer and follow-up fertilizer, respectively; (7) one application of urea fertilizer (DU1) and two applications of follow-up urea (DU2) through drip irrigation, of which 16.7% and 4.6% of N in the basal and follow-up fertilizers of FO1, DO1, and DO2 were supplied by organic fertilizers, respectively. The plot area was 102.6 m^2 (2.7 m × 38 m). A 2 m buffer zone was established between each treatment. All treatments were organized using a randomized complete block design, with each treatment replicated three times. There was also a N blank treatment with basal application of calcium superphosphate (P_2O_5 12%) and potassium chloride (K_2O 60%). Phosphorus fertilizer, potassium fertilizer, and solid organic fertilizer (alginate bio-organic fertilizer, N + P_2O_5 + K_2O ≥ 5%, organic matter ≥ 45%, Shandong Enbao Biotechnology Co., Ltd., Qingdao, China) were applied as basal fertilizer at one time, and organic water-soluble fertilizer (N + P_2O_5 + K_2O ≥ 120 g/L, organic matter ≥ 60 g/L, Shandong Enbao Biotechnology Co., Ltd., Qingdao, China) was applied as a follow up fertilizer by drip irrigation. In 2020–2021, the seeding was sown on 28 October, harvested, and measured for yields on 18 June with a seeding rate of 262.5 kg/ha. In 2021–2022, seeds were sown on 25 October and harvested on 17 June with a seeding rate of 240.0 kg/ha. Other cultivations were managed following the local wheat cultural practices. The precipitation recorded for the two growing seasons was 237.6 mm and 145.1 mm, respectively (Figure 1).

Table 1. The amount of fertilizers used and irrigation amount in each growth period of winter wheat.

Treatments	Irrigation Volumes (mm)		Amount of Base Fertilizer N Used		Amount of N Used		Total N Used (kg/ha)	Irrigation Method
	Jointing	Flowering	Chemical Fertilizer	Organic Fertilizer	Jointing Chemical Fertilizer and Organic Water-Soluble Fertilizer	Flowering Chemical Fertilizer and Organic Water-Soluble Fertilizer		
CK	45	30	135	0	105 + 0	0 + 0	240	Sprinkler
FU1	45	30	72	0	108 + 0	0 + 0	180	Sprinkler
FO1	45	30	60	12	103 + 5	0 + 0	180	Furrow
DO1	45	30	60	12	103 + 5	0 + 0	180	Drip
DO2	45	30	60	12	62 + 3	41 + 2	180	Drip
DU1	45	30	72	0	108 + 0	0 + 0	180	Drip
DU2	45	30	72	0	65 + 0	43 + 0	180	Drip

The inorganic nitrogen, solid organic nitrogen, and liquid organic nitrogen were, respectively, supplied by urea (46% N), alginate bio-organic fertilizer, and organic water-soluble fertilizer. The amount of nitrogen fertilizer was based on previous research [2,10,13].

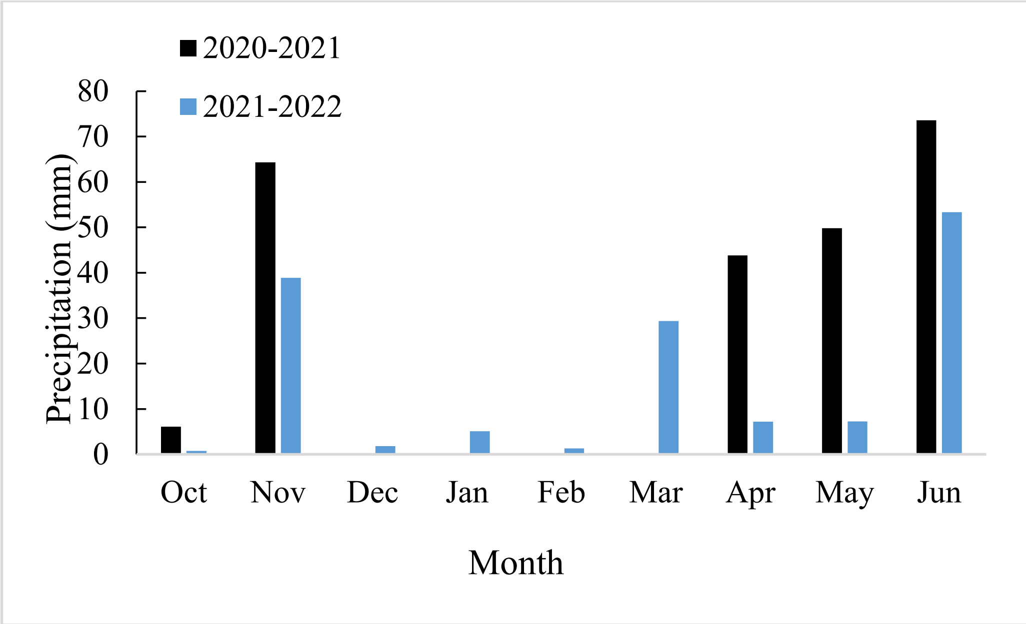

Figure 1. Changes in precipitation during wheat fertility in both 2020 and 2022.

2.2. Sampling and Measurements

2.2.1. Dry Matter Accumulation and Nitrogen Utilization

Thirty uniform tillers were taken from wheat plants at various stages of nodulation, pregnancy, tasseling, flowering, grouting, and ripening, respectively. They were grouped by different organs, placed in an oven, dehydrated at 105 °C for 30 min, and then dried at 80 °C to a constant weight. The total nitrogen content of each wheat organ was determined using the H_2SO_4-H_2O_2 digestion method with an AA3 flow analyzer, and the N uptake and utilization indices of each organ were calculated (SEAL, Hamburg, Germany) [21].

Pre-anthesis translocation amount (PTA; kg/ha) = Dry weight of vegetative organs at anthesis − Dry weight of vegetative organs at maturity

Contribution of pre-anthesis translocation to grains (CPT; %) = Translocation of dry matter in pre-anthesis vegetative organs/Dry weight of grains at maturity × 100

Post-anthesis accumulation amount (PAA; kg/ha) = Dry weight at maturity − Dry weight at anthesis

Post-anthesis accumulation amount of grain (PAAG; kg/ha) = Dry matter quality of plants at maturity − Dry matter quality of plants at flowering

Contribution of post-anthesis accumulation to grains (CPA; %) = Post-anthesis accumulation of dry matter/Dry weight of grains at maturity × 100

N use efficiency (NUE, kg/kg) = Grain yield/aboveground N accumulation

N uptake efficiency (NUPE, kg/kg) = aboveground N accumulation/application of N

N harvest index (NHI, %) = (total grain N accumulation/plant N accumulation) × 100

Apparent N use efficiency (ANUE, %) = (N accumulation of plants in N applied area − N accumulation of plants in no N applied area)/N applied × 100

N agronomic efficiency (NAE, kg/kg) = (Yield of N application area − Yield without N application area)/N applied

2.2.2. Grain Filling Rate

Thirty spikes were taken at 5-day intervals after anthesis, and the middle kernel of each spike was dried and weighed; the rate of seed filling was calculated:

Grain filling rate = (dry weight of the latter seed - dry weight of the former seed)/number of days in between

2.2.3. Yield Formation and Quality Indicators

Wheat plants in 1 m wide double rows were collected at harvest, and the number of spikes, number of grains per spike, thousand-grain weight, and yield per hectare were counted or measured. A near-infrared grain analyzer was used to determine the wheat grain weight, hardness, and other seed indexes. A MOULINCD1 automatic gluten cleaner, a gluten index tester (gluten centrifugal extractor), and a gluten dryer were used to determine the wet gluten index; a flour stretching machine was used to determine the quality of the dough, while a Kjeldahl N tester was used to determine the protein content in seeds.

2.3. Data Analysis

Analysis of variance was conducted using SPSS 20.0, with significance assessed at the 0.05 level (Duncan). Data processing and chart creation were performed using Microsoft Excel 2019.

3. Results

3.1. Effect of Nitrogen Reduction with Organic Fertilizer on Dry Matter Transport in Winter Wheat

There were no significant differences in the PTA and CPT between the N reduction treatments and CK (Table 2). PTA was significantly increased by 27.1% and 24.5% in the DO2 treatment compared with the N-reduced FU1 and FO1 treatments through furrow irrigation, respectively. The PAA in the FU1 treatment was significantly lower than that in the other treatments, ranging from 19.0% to 33.0%; the DO2 treatment had the highest amount of 6982.7 kg/ha, which was significantly higher than that of CK, FU1, FO1, DO1, DU1, and DU2, which were significantly higher by 15.5%, 49.2%, 20.9%, 11.7%, 16.3% and 7.9%. With the follow-up application of organic fertilizer, the PAAG was DO2 > DO1 > FO1, and the split fertilization was preferred to the single fertilization. Compared with CK, the CPA was significantly reduced by 10.5% with the FU1 treatment.

Table 2. Effect of the nitrogen reduction by use of the organic fertilizer on transporting dry matter in winter wheat (2020–2021).

Treatments	PTA (kg/ha)	CPT (%)	PAA (kg/ha)	PAAG (kg/ha)	CPA (%)
CK	2930.3 ± 740.26 ab	32.4 ± 6.71 a	6045.8 ± 268.59 bc	4199.3 ± 655.29 b	46.6 ± 4.94 a
FU1	2669.0 ± 235.62 b	36.3 ± 2.72 a	4680.0 ± 240.44 d	3063.8 ± 211.18 c	41.7 ± 1.27 b
FO1	2723.7 ± 137.57 b	32.0 ± 1.48 a	5777.4 ± 185.83 c	4114.9 ± 165.99 b	48.4 ± 0.96 a
DO1	2782.8 ± 106.45 ab	30.8 ± 0.29 a	6249.1 ± 159.11 bc	4202.8 ± 330.82 b	46.5 ± 2.75 a
DO2	3391.5 ± 53.03 a	32.7 ± 0.99 a	6982.7 ± 408.12 a	4909.6 ± 359.43 a	47.3 ± 1.49 a
DU1	2887.4 ± 371.36 ab	32.4 ± 3.51 a	6002.9 ± 230.70 bc	4257.9 ± 72.99 b	47.9 ± 0.98 a
DU2	2947.2 ± 257.22 ab	31.3 ± 0.90 a	6469.1 ± 379.49 b	4606.4 ± 704.69 ab	48.7 ± 4.45 a

Note: Different lowercase letters represent significant differences between different treatments ($p < 0.05$).

3.2. Effect of Nitrogen Reduction and Organic Fertilizer Application on Grain Grouting Rate of Winter Wheat Kernels

All treatments had a certain effect on the duration of wheat grain filling (Figure 2). The wheat grain grouting rate first increased and then declined. During the period of the first 10 days of grouting, the grouting rate of CK was the highest and then gradually decreased, while the highest grouting rate of the inorganic treatments (FO1, DO1, DO2) and the urea treatments through drip irrigation (FU1, DU1, DU2) were within 15 and 20 days, respectively, among which the grouting rate of DO1 was significantly higher than other treatments. At 10 days, the grain filling rate in the CK treatment reached its peak, showing an increase of 0.21% to 4.61% compared with other treatments. By 15 days, the DO1 treatment exhibited the highest grain filling rate, which was 2.2% to 3.31% greater than in other treatments. At 20 days, the DU1 treatment demonstrated the highest rate, with an increase of 1.03% to 6.01% over other treatments. These variations in the grain filling rate may be attributed to differences in nitrogen fertilizer applications and the increased rainfall during the grain filling period.

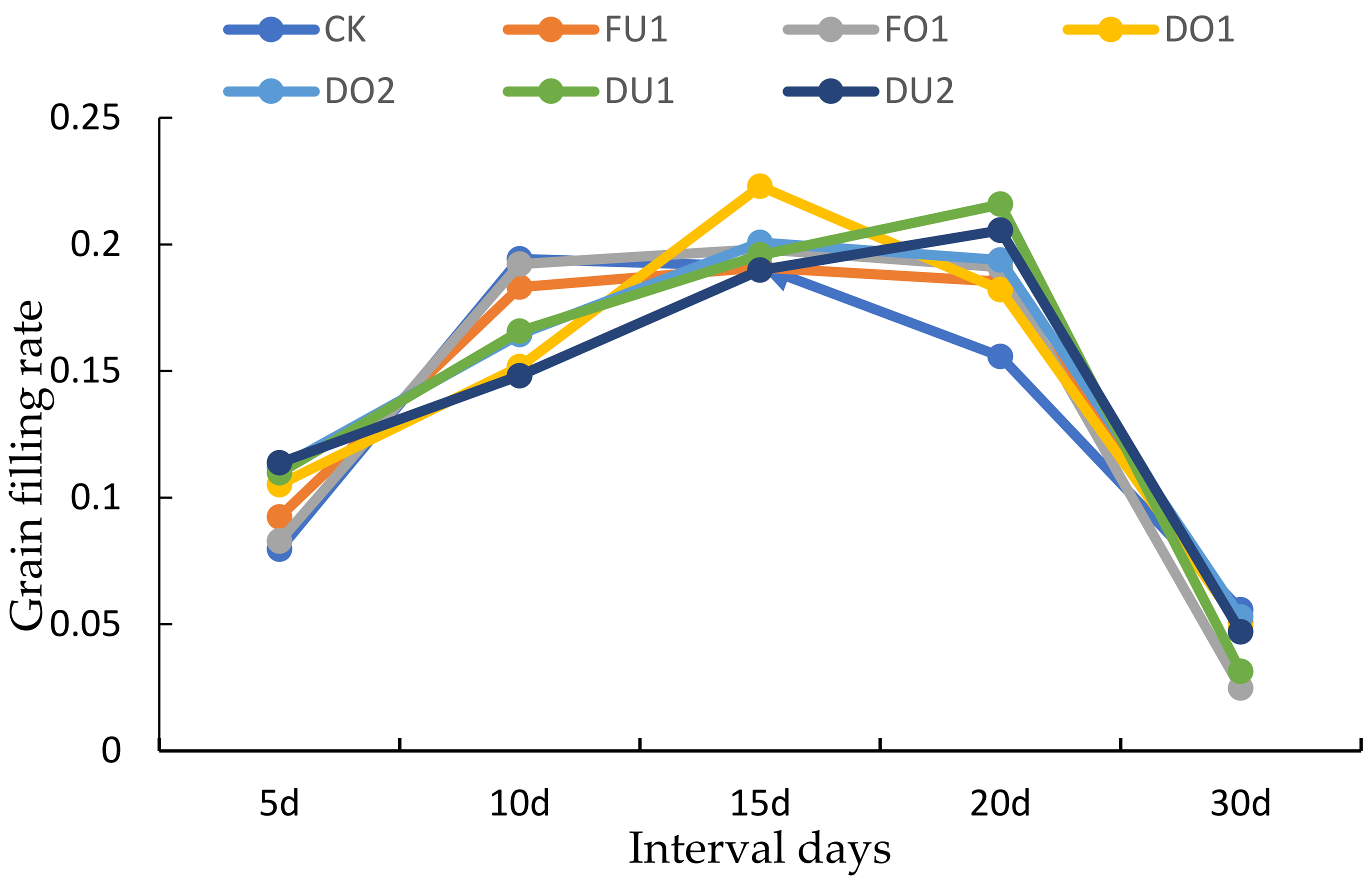

Figure 2. Effect of the nitrogen reduction combined with organic fertilizer on the grain filling rate in winter wheat (2020–2021).

3.3. Effect of Nitrogen Reduction with Organic Fertilizer on Winter Wheat Yield

The different fertilization treatments had certain effects on the yield of wheat and its related factors from 2020 to 2021, and the DO2 treatment had the higher yield of 11.7 t/ha (Table 3). The thousand-grain weight, yield, and harvest index of wheat with the DO1 and DO2 treatments were significantly higher than those with the CK treatment, where the number of grain per spike, thousand-grain weight with the DO2 treatment, yield, and harvest index were 22.9%, 7.7%, 51.3%, and 38.0% higher than the CK treatment, respectively. Within the treatments of N reduction plus urea application, the yield with the DU1 and DU2 treatments were 39.6% and 60.3% significantly higher than that with FU1, respectively. Within the treatments of two applications of follow-up fertilizer, the yield with the DO2 treatment was slightly higher than that of the DU2 treatment. In the 2021–2022 season, the measurements of yield and yield-related parameters with each treatment were similar to those obtained in the season, while the number of grains per spike, thousand-grain weight, yield, and harvest index of the treatments with an application of follow-up organic fertilizer through drip irrigation were significantly higher than those of CK. However, the average of the above indicators was lower than that of the data from the first year.

Table 3. Effect of the nitrogen reduction combined with organic fertilizer on the yield and other related parameters in winter wheat.

Year	Treatments	Spike Number ($\times 10^4$/ha)	Grain per Spike	Thousand-Grain Weight (g)	Yield (t/ha)	Harvest Index (%)
2020–2021	CK	605.4 ± 46.10^{ab}	29.7 ± 1.24^{c}	43.1 ± 0.97^{b}	7.8 ± 0.99^{cd}	40.8 ± 4.42^{b}
	FU1	521.4 ± 46.61^{b}	29.5 ± 0.70^{c}	44.5 ± 1.65^{ab}	6.8 ± 1.48^{d}	38.8 ± 5.82^{b}
	FO1	646.7 ± 47.6^{ab}	31.5 ± 2.04^{bc}	45.0 ± 1.25^{ab}	9.1 ± 0.96^{bc}	48.8 ± 4.83^{ab}
	DO1	670.0 ± 47.26^{ab}	32.4 ± 1.59^{bc}	45.2 ± 1.29^{a}	9.8 ± 0.83^{abc}	53.7 ± 6.90^{a}
	DO2	700.7 ± 52.99^{a}	36.5 ± 0.56^{a}	46.4 ± 0.15^{a}	11.7 ± 1.08^{a}	56.3 ± 5.17^{a}
	DU1	668.0 ± 49.71^{ab}	32.1 ± 1.97^{bc}	44.9 ± 1.97^{ab}	9.5 ± 0.84^{bc}	48.5 ± 5.51^{ab}
	DU2	684.7 ± 51.93^{ab}	35.6 ± 1.25^{ab}	44.8 ± 1.32^{ab}	10.9 ± 0.92^{ab}	53.3 ± 6.38^{a}
2021–2022	CK	584.8 ± 25.25^{ab}	26.4 ± 1.49^{d}	38.6 ± 1.33^{b}	8.3 ± 0.69^{b}	48.2 ± 2.33^{b}
	FU1	521.4 ± 10.33^{c}	28.8 ± 0.69^{c}	37.3 ± 3.70^{b}	6.2 ± 0.14^{d}	48.7 ± 1.63^{b}
	FO1	593.4 ± 10.24^{ab}	31.6 ± 2.76^{b}	37.8 ± 0.70^{b}	8.3 ± 0.05^{b}	53.4 ± 4.91^{ab}
	DO1	596.9 ± 9.57^{ab}	32.7 ± 0.87^{b}	43.1 ± 1.70^{a}	9.9 ± 1.05^{a}	51.3 ± 4.92^{ab}
	DO2	614.0 ± 7.78^{a}	36.3 ± 0.89^{a}	42.8 ± 0.83^{a}	10.9 ± 0.36^{a}	57.3 ± 2.86^{a}
	DU1	590.6 ± 16.39^{ab}	32.6 ± 0.58^{b}	36.7 ± 2.14^{b}	7.9 ± 0.15^{c}	52.2 ± 5.14^{ab}
	DU2	579.4 ± 24.53^{b}	33.3 ± 0.49^{b}	38.7 ± 0.48^{b}	8.0 ± 0.32^{c}	54.8 ± 2.01^{ab}

Note: Different lowercase letters represent significant differences between different treatments ($p < 0.05$).

3.4. Effect of Nitrogen Reduction Plus Organic Fertilizer on Nitrogen Uptake and Utilization in Winter Wheat

As shown in Table 4, the effect of different organic–inorganic fertilizer treatments on N uptake and utilization in wheat varied significantly between the two years. The NUPE of wheat with all drip irrigation plus fertilization treatments was significantly improved by 20.8% to 50.0% compared with that of the conventional irrigation plus fertilization treatments. Compared with CK, the N UE with the DO2 and DU2 treatments increased significantly by 36.6% and 35.3%, respectively. The NAE also differed among different fertilization treatments, with which the CK and FU1 treatments had a significantly lower efficiency than that of other treatments. The difference in the ANUE between the treatments of organic water-soluble fertilizers reached a significant level, and the size of the relationship showed that DO2 > DO1 > FO1, while the N reduction between the treatments of urea application was DU2 > DU1 > FU1, and the NUPE of the drip irrigation treatments was significantly higher than that of the diffuse irrigation treatments. Compared with CK, the NHI of the treatments with a follow-up application of organic fertilizers (DO1 and DO2) through drip irrigation was increased by 1.8% and 3.5%, respectively. Similar to the first year's data analysis, a better N uptake was seen with the drip irrigation treatments, especially when the follow-up application of organic water-soluble fertilizers was applied in the 2021–2022 season. Multiple fertilizer applications (DO2 and DU2) demonstrated a higher NUPE than that of a single application (DO1 and DU1). In addition, a higher NUE, NAE, ANUE, and NHI of treatments (FO1, DO1, and DO2) with organic water-soluble fertilizer applications were observed, compared to those of the treatments with urea application (CK, FU1, DU1, and DU2).

Table 4. Effect of the nitrogen reduction with organic fertilizer generation on nitrogen uptake and utilization in winter wheat.

Year	Treatments	NUPE (kg/kg)	NUE (kg/kg)	NAE (kg/kg)	ANUE (%)	NHI (%)
2020–2021	CK	1.06 ± 0.03 [f]	23.8 ± 4.21 [b]	8.8 ± 4.50 [c]	18.7 ± 6.54 [d]	82.7 ± 0.47 [cd]
	FU1	1.28 ± 0.03 [e]	23.3 ± 2.71 [b]	6.6 ± 1.44 [c]	10.7 ± 4.80 [e]	83.3 ± 0.35 [bc]
	FO1	1.35 ± 0.04 [d]	28.7 ± 3.76 [ab]	19.3 ± 4.13 [b]	18.0 ± 3.02 [d]	83.6 ± 0.21 [bc]
	DO1	1.44 ± 0.03 [c]	29.6 ± 5.22 [ab]	23.3 ± 7.19 [b]	26.9 ± 5.19 [c]	84.2 ± 0.53 [b]
	DO2	1.59 ± 0.01 [a]	32.5 ± 1.94 [a]	33.9 ± 2.60 [a]	42.1 ± 5.42 [a]	85.6 ± 0.24 [a]
	DU1	1.42 ± 0.03 [c]	29.1 ± 3.54 [ab]	21.6 ± 4.00 [b]	24.8 ± 7.13 [c]	82.3 ± 0.76 [d]
	DU2	1.50 ± 0.03 [b]	32.2 ± 4.70 [a]	29.4 ± 6.86 [a]	32.9 ± 1.83 [b]	83.7 ± 0.88 [bc]
2021–2022	CK	1.03 ± 0.02 [f]	23.4 ± 0.28 [d]	9.2 ± 0.33 [e]	16.4 ± 0.97 [e]	83.3 ± 0.76 [bc]
	FU1	1.27 ± 0.03 [e]	20.5 ± 1.14 [e]	8.0 ± 0.34 [f]	12.3 ± 0.44 [f]	83.7 ± 1.05 [b]
	FO1	1.36 ± 0.03 [de]	26.1 ± 0.43 [c]	22.3 ± 0.63 [c]	26.2 ± 0.34 [c]	83.7 ± 0.99 [b]
	DO1	1.4 ± 0.05 [bc]	29.1 ± 0.27 [b]	24.8 ± 0.47 [b]	32.2 ± 0.25 [b]	84.8 ± 0.05 [ab]
	DO2	1.58 ± 0.09 [a]	32.3 ± 0.60 [a]	26.9 ± 0.25 [a]	40.1 ± 1.09 [a]	85.3 ± 0.99 [a]
	DU1	1.42 ± 0.02 [cd]	24.9 ± 0.66 [d]	16.6 ± 0.60 [d]	22.2 ± 0.84 [d]	81.9 ± 0.88 [c]
	DU2	1.52 ± 0.08 [ab]	26.6 ± 0.47 [c]	24.8 ± 0.07 [b]	28.4 ± 5.72 [bc]	83.9 ± 0.69 [ab]

Note: Different lowercase letters represent significant differences between different treatments ($p < 0.05$).

3.5. Effect of Nitrogen Reduction with Organic Fertilizer on Winter Wheat Quality

Different fertilization methods and types of N application would affect the grain, flour, and dough quality of wheat. In the 2020–2021 season, the protein content, dough stability time, development time, and tensile area within the treatments differed from those of CK (Table 5). The protein content with one application of reduced nitrogen fertilizer (FU1, DO1, DU1) except for the treatments of reduced N fertilizer (DO2, DU2) was significantly lower than that of CK by 5.4%, 3.9%, and 4.7%, respectively. With the treatments of N reduction and follow-up organic fertilizer application, the flour yield with the DO2 treatment was 6.1% and 7.3% significantly higher than that of CK and FU1, respectively. In terms of flour quality, the DO2 treatment had a significantly higher sedimentation volume of 6.6% compared with that of FU1, while the DU2 treatment had the lowest water absorption and undifferentiated wet gluten content among the treatments. The extensibility and tensile area were significantly increased by 7.5% and 11.8% with the DO2 treatment compared to CK. Dough maximum resistance to extension with the DO1 and DO2 treatments were significantly increased by 8.5% and 9.8% compared to FU1 treatment. In the 2021–2022 season, there was no significant difference in hardness, flour yield, sedimentation volume, wet gluten content, water absorption ductility, and maximum resistance to extension among treatments. The dough stability time and development time of the treatments showed similar trends to the first year, both of which were highest in the control, while the protein content, test weight, and tensile area of the treatments had different trends from the results of the first year of the experiment. The treatment of follow-up application of organic water-soluble fertilizer through drip irrigation (DO1 and DO2) had higher measurements with those quality-related parameters.

Table 5. Effect of the nitrogen reduction combined with organic fertilizer on the quality of winter wheat.

Year	Treatments	Grain Quality				Flour Quality			Dough Quality				
		Protein Content (%)	Test Weight (g/L)	Hardness (%)	Flour Yield (%)	Sedimentation Volume (mL)	Wet Gluten (%)	Water Absorption (%)	Extensibility (mm)	Stability Time (min)	Development Time (min)	Tensile Area (cm^2)	Maximum Ductility resistance (BU)
2020–2021	CK	12.9 ± 0.14 ^{a}	792.1 ± 5.68 ^{a}	48.0 ± 0.85 ^{ab}	62.6 ± 1.58 ^{b}	35.3 ± 1.67 ^{ab}	33.6 ± 2.46 ^{a}	58.4 ± 0.79 ^{ab}	147.6 ± 5.49 ^{b}	2.53 ± 0.25 ^{a}	5.93 ± 0.27 ^{a}	91.6 ± 4.33 ^{b}	312.1 ± 9.24 ^{ab}
	FU1	12.2 ± 0.17 ^{b}	794.0 ± 7.01 ^{a}	49.0 ± 0.05 ^{a}	61.9 ± 2.06 ^{b}	34.9 ± 0.61 ^{b}	33.6 ± 1.17 ^{a}	59.5 ± 1.30 ^{a}	148.4 ± 2.44 ^{b}	2.00 ± 0.13 ^{c}	4.57 ± 0.19 ^{bc}	94.7 ± 4.12 ^{ab}	300.5 ± 9.00 ^{b}
	FO1	12.5 ± 0.13 ^{ab}	794.5 ± 6.08 ^{a}	48.9 ± 1.49 ^{a}	63.5 ± 0.90 ^{ab}	36.6 ± 1.30 ^{ab}	33.9 ± 3.04 ^{a}	59.5 ± 0.98 ^{a}	151.7 ± 4.33 ^{ab}	2.10 ± 0.00 ^{bc}	4.23 ± 0.14 ^{c}	95.8 ± 4.23 ^{ab}	316.2 ± 9.48 ^{ab}
	DO1	12.4 ± 0.37 ^{b}	792.0 ± 15.90 ^{a}	47.6 ± 1.02 ^{ab}	64.9 ± 2.96 ^{ab}	36.2 ± 0.09 ^{ab}	34.2 ± 2.14 ^{a}	58.4 ± 0.20 ^{ab}	149.6 ± 5.38 ^{ab}	2.37 ± 0.1 ^{ab}	5.23 ± 0.23 ^{abc}	100.0 ± 4.35 ^{ab}	326.1 ± 16.00 ^{a}
	DO2	12.5 ± 0.53 ^{ab}	793.8 ± 37.77 ^{a}	47.8 ± 1.46 ^{ab}	66.4 ± 0.92 ^{a}	37.2 ± 0.43 ^{a}	34.7 ± 3.46 ^{a}	58.9 ± 0.38 ^{ab}	158.6 ± 2.96 ^{a}	2.10 ± 0.02 ^{bc}	5.43 ± 0.36 ^{ab}	102.4 ± 3.68 ^{a}	329.8 ± 14.26 ^{a}
	DU1	12.3 ± 0.25 ^{b}	794.3 ± 6.28 ^{a}	48.8 ± 0.60 ^{a}	63.9 ± 2.25 ^{ab}	36.8 ± 0.69 ^{ab}	34.1 ± 4.30 ^{a}	59.6 ± 0.35 ^{a}	151.6 ± 3.46 ^{ab}	2.17 ± 0.15 ^{bc}	4.60 ± 0.45 ^{bc}	95.4 ± 3.05 ^{ab}	317.0 ± 17.57 ^{ab}
	DU2	12.5 ± 0.2 ^{ab}	792.7 ± 18.58 ^{a}	46.9 ± 0.32 ^{b}	65.4 ± 3.73 ^{ab}	37.0 ± 1.67 ^{ab}	34.6 ± 3.77 ^{a}	57.8 ± 0.61 ^{b}	151.5 ± 3.82 ^{ab}	2.30 ± 0.25 ^{abc}	5.13 ± 0.44 ^{abc}	98.4 ± 7.89 ^{ab}	324.1 ± 7.14 ^{ab}
2021–2022	CK	12.8 ± 0.37 ^{ab}	818.3 ± 20.42 ^{abc}	48.9 ± 5.90 ^{a}	64.1 ± 3.15 ^{a}	36.7 ± 3.41 ^{a}	34.1 ± 4.38 ^{a}	60.6 ± 4.01 ^{a}	141.1 ± 7.83 ^{a}	2.45 ± 0.03 ^{a}	5.37 ± 0.37 ^{a}	71.3 ± 3.65 ^{c}	327.5 ± 17.79 ^{a}
	FU1	12.7 ± 0.34 ^{ab}	767.6 ± 4.04 ^{bc}	48.2 ± 3.74 ^{a}	56.7 ± 6.13 ^{a}	34.2 ± 2.03 ^{a}	35.7 ± 2.59 ^{a}	59.3 ± 3.46 ^{a}	143.0 ± 10.38 ^{a}	1.85 ± 0.20 ^{c}	4.45 ± 0.37 ^{cd}	76.4 ± 5.56 ^{bc}	313.2 ± 4.35 ^{a}
	FO1	12.6 ± 0.66 ^{ab}	832.1 ± 25.77 ^{ab}	49.5 ± 2.6 ^{a}	62.0 ± 3.55 ^{a}	37.3 ± 3.30 ^{a}	36.4 ± 4.43 ^{a}	60.4 ± 3.26 ^{a}	136.2 ± 3.23 ^{a}	1.85 ± 0.14 ^{c}	4.41 ± 0.02 ^{d}	87.7 ± 4.74 ^{ab}	332.8 ± 13.05 ^{a}
	DO1	13.3 ± 0.53 ^{ab}	851.2 ± 17.33 ^{a}	48.8 ± 3.19 ^{a}	64.6 ± 4.10 ^{a}	38.8 ± 2.64 ^{a}	36.8 ± 3.87 ^{a}	60.2 ± 4.55 ^{a}	136.5 ± 9.94 ^{a}	2.32 ± 0.17 ^{ab}	4.61 ± 0.22 ^{cd}	91.5 ± 4.48 ^{a}	333.5 ± 16.86 ^{a}
	DO2	13.8 ± 0.83 ^{a}	852.0 ± 17.68 ^{a}	53.1 ± 2.86 ^{a}	65.4 ± 4.47 ^{a}	39.6 ± 2.82 ^{a}	37.3 ± 4.06 ^{a}	61.7 ± 3.89 ^{a}	148.7 ± 6.25 ^{a}	2.33 ± 0.14 ^{ab}	5.06 ± 0.20 ^{ab}	94.3 ± 4.28 ^{a}	335.5 ± 13.02 ^{a}
	DU1	12.3 ± 0.66 ^{b}	763.2 ± 8.53 ^{c}	45.8 ± 2.88 ^{a}	57.7 ± 5.97 ^{a}	35.0 ± 3.15 ^{a}	35.6 ± 5.20 ^{a}	59.9 ± 6.59 ^{a}	150.3 ± 5.37 ^{a}	1.98 ± 0.13 ^{bc}	4.36 ± 0.08 ^{d}	71.2 ± 2.54 ^{c}	323.0 ± 6.10 ^{a}
	DU2	12.6 ± 0.81 ^{ab}	825.7 ± 15.97 ^{abc}	46.7 ± 3.85 ^{a}	60.3 ± 3.80 ^{a}	35.0 ± 2.31 ^{a}	37.1 ± 3.85 ^{a}	58.1 ± 5.39 ^{a}	135.5 ± 8.29 ^{a}	1.97 ± 0.15 ^{bc}	4.86 ± 0.20 ^{bc}	85.9 ± 5.31 ^{ab}	332.7 ± 5.17 ^{a}

Note: Different lowercase letters represent significant differences between different treatments ($p < 0.05$).

4. Discussion

During the whole cultivation of winter wheat, an appropriate reduction of N fertilizer can improve the photosynthetic performance of leaves and also be conducive to the enhancement of wheat DMA, NUPE, and so on, which will lead to an increase in yield [22]. An alternative application of organic and inorganic fertilizers to reduce N use suggests that the use of 20% organic fertilizer to substitute the N source is more prone to increase the wheat yield and NUE when the total amount of N used during the whole season is 200 kg/ha [23]. Moreover, an optimized reduction in N fertilizer through drip irrigation has proven to increase the DMA, N transfer efficiency, and activities of key enzymes involved in the N metabolism of spring wheat, enhance the grain grouting, and thus increase the yield [24], which is similar to the results derived from this experiment. The data analyses have demonstrated that the transfer of dry matter to nutritive organs was significantly higher in wheat plants with the DO2 treatment than that of two treatments with surface irrigation (FU1, FO1), indicating the combination of N fertilization and drip irrigation in DO2 was more appropriate for the DMA, their transfer, other yield-related parameters, and yield than that in CK in winter wheat. There is strong evidence that drip irrigation is better than traditional fertilization through surface irrigation and should be more preferred to recover N from organic fertilizers for a moderate N reduction and incremental grain production, probably due to improved soil conditions by drip irrigation [25]. Moreover, drip irrigation was used in this study to replace some inorganic fertilizers as follow-up fertilizers, which may have amended physicochemical properties and microbes in soil during the middle and late growing stages to improve wheat productivity. Also, we believe that precipitation amount and timing might have played a role in affecting wheat yield and other yield-related parameters since their measurements in the 2020–2021 growing season were generally higher than those of CK, likely due to 92.8 mm more precipitation than in the 2021–2022 season (Figure 1). A similar observation was reported, suggesting that more precipitation can facilitate more grouting and dry matter accumulation in time [26]. However, it is evident that the ratio of substituted organic N for inorganic N fertilizer, N delivery method, duration of substituted N, and weather conditions can impact greatly on wheat growth and production; therefore, more complex, well-designed, detailed, and in-depth studies need to be carried out according to specific interests and environmental conditions.

While improving soil fertility, organic fertilizers can reduce the nitrate N content in soil, increase the efficiency of N fertilizer utilization, and enhance wheat yield [15,27]. The combined application of organic and inorganic fertilizers can significantly increase wheat nitrogen accumulation and yield compared to traditional fertilization methods [14,18]. N reduction through the application of organic fertilizers can improve the agronomic efficiency of N fertilizer in wheat production and significantly increase the DMA for more grain yield [28]. In this study, it was found that the difference in the impact of different numbers of topdressing applications on nitrogen harvest index is significant, and the relationship between the two years' data showed that DO2 > DO1 > DU2 > FO1 $\geq$ FU1 > CK > DU1. The DO2 treatment improved the NUPE and NUE significantly by 50.0% and 36.6%, respectively, in comparison with CK (2021–2022), probably due to the fact that the N fertilizer utilization efficiency was improved by the application of organic N fertilizer through drip irrigation. Throughout the whole wheat growing season, the use of drip irrigation to deliver fertilizers for a reasonable reduction in N fertilizers has been proven to mitigate a potential N loss and improve the UPE and NUE for more wheat grains [29]. Previous research has demonstrated that a moderate replacement of inorganic fertilizers with organic ones [30], especially for the replacement of urea with organic water-soluble fertilizers in follow-up fertilization through drip irrigation used in this study, also has a positive effect on wheat growth and production, and both approaches may have effectively improved the N utilization efficiency and yield in this study.

An appropriate increase in nitrogen application rates contributed to the enhanced yield and quality of winter wheat. Quality parameters such as crude protein content, wet gluten content, and sedimentation value showed significant improvement when the nitrogen application rate ranged from 150 to 210 kg/ha [2]. The use of organic fertilizer has been attempted repeatedly to improve wheat quality and obtain high yield in addition to the conventional fertilization approach [31] and has currently been used to do so for inorganic fertilizer reduction and quality improvement [32]. Our results have shown that a N reduction of 25% with organic replacement fertilizer (DO2, DU2) increased the wheat flour yield, dough extensibility, tensile area, and maximum resistance to extension as indicators of dough quality. It has been suggested that the organic fertilizer with N source resulted in a simultaneous improvement of the yield and quality of winter wheat and an enhancement of soil biological properties [33]. Mule et al. [34] also reported that the application of bio-organic fertilizer was beneficial for increasing wheat yield and enhancing wheat protein content, gluten content, protein yield, and other indexes. However, some research has also suggested that the long-term application of organic fertilizer is not beneficial for improving wheat quality [35]. The difference in the wheat capacity and wet gluten content between treatments in this study is not significant; however, whether there is a correlation between the capacity and wet gluten content and their response to water and N transport remains unknown and needs to be further investigated. According to our data analyses, the protein content, capacity, and hardness in kernel or grains vary between two seasons, and the variations may well be due to the fluctuation of precipitation in different years, especially during late flowering and grouting stages as suggested by a recent report [36]. More precipitation and other weather data throughout the different stages of the wheat growing season should be collected and their effect on all growth- and yield-related parameters analyzed to further understand the impact of weather conditions on wheat production and grain quality in association with the optimized use of both inorganic and organic fertilizers.

5. Conclusions

In comparison with traditional irrigation and fertilization, a reduction of 25% N in inorganic fertilizer use (FU1) was not sufficient for normal wheat growth. With 25% N reduction through an application of organic fertilizer, the one-time application of organic water-soluble fertilizer (DO2) at the nodulation and flowering stage had a significant effect on the DMA, NHI, and yield. The DO2 treatment also increased wheat flour yield, dough extensibility, tensile area, and maximum resistance to extension and improved dough quality. Therefore, with a 25% N reduction as the basal fertilization with the organic fertilizer through drip irrigation of organic water-soluble fertilizer twice can be used as an eco-friendly, high-quality, and high-yield fertilization program for winter wheat.

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References

1. Hu, N.; Du, C.; Zhang, W.; Liu, Y.; Zhang, Y.; Zhao, Z.; Wang, Z. Did Wheat Breeding Simultaneously Improve Grain Yield and Quality of Wheat Cultivars Releasing over the Past 20 Years in China? *Agronomy* **2022**, *12*, 2109. [CrossRef]
2. Litke, L.; Gaile, Z.; Ruža, A. Effect of nitrogen fertilization on winter wheat yield and yield quality. *Agron. Res.* **2018**, *16*, 500–509. [CrossRef]

3. Wang, Y.-J.; Tao, Z.-Q.; Wang, D.-M.; Wang, Y.-J.; Yang, Y.-S.; Zhao, G.-C.; Shi, S.-B.; Chang, X.-H. An economic and viable approach to improve wheat quality in Qinghai–Tibetan Plateau, China. *J. Integr. Agric.* **2022**, *21*, 2227–2240. [CrossRef]
4. Zhang, W.F.; Dou, Z.X.; He, P.; Ju, X.T.; Powlson, D.; Chadwick, D.; Norse, D.; Lu, Y.L.; Zhang, Y.; Wu, L.; et al. New technologies reduce greenhouse gas emissions from nitrogenous fertilizer in China. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 8375–8380. [CrossRef] [PubMed]
5. Yao, C.S.; Ren, J.; Li, H.R.; Zhang, Z.; Wang, Z.M.; Sun, Z.C.; Zhang, Y.H. Can wheat yield, N use efficiency and processing quality be improved simultaneously? *Agric. Water Manag.* **2023**, *275*, 108006. [CrossRef]
6. Zhen, S.M.; Deng, X.; Xu, X.X.; Liu, N.N.; Zhu, D.; Wang, Z.M.; Yan, Y.M. Effect of high-nitrogen fertilizer on gliadin and glutenin subproteomes during kernel development in wheat (*Triticum aestivum* L.). *Crop J.* **2020**, *8*, 38–52. [CrossRef]
7. Janczak-Pieniazek, M.; Buczek, J.; Jarecki, W.; Bobrecka-Jamro, D. Effect of High Nitrogen Doses on Yield, Quality And Chemical Composition Grain of Winter Wheat Cultivars. *J. Elem.* **2020**, *25*, 1005–1017. [CrossRef]
8. Wang, J.; Sun, X.; Hussain, S.; Yang, L.; Gao, S.; Zhang, P.; Chen, X.; Ren, X. Reduced nitrogen rate improves post-anthesis assimilates to grain and ameliorates grain-filling characteristics of winter wheat in dry land. *Plant Soil* **2023**, *49*, 91–112. [CrossRef]
9. Latiri-Souki, K.; Nortcliff, S.; Lawlor, D.W. Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiencies for durum wheat under semi-arid conditions. *Eur. J. Agron.* **1998**, *9*, 21–34. [CrossRef]
10. Yao, C.; Li, J.; Zhang, Z.; Liu, Y.; Wang, Z.; Sun, Z.; Zhang, Y. Improving wheat yield, quality and resource utilization efficiency through nitrogen management based on micro-sprinkler irrigation. *Agric. Water Manag.* **2023**, *282*, 108277. [CrossRef]
11. Liu, Y.; Liao, Y.; Liu, W. High nitrogen application rate and planting density reduce wheat grain yield by reducing filling rate of inferior grain in middle spikelets. *Crop J.* **2021**, *9*, 412–426. [CrossRef]
12. Fan, Y.; Qin, B.; Yang, J.; Ma, L.; Cui, G.; He, W.; Tang, Y.; Zhang, W.; Ma, S.; Ma, C.; et al. Night warming increases wheat yield by improving pre-anthesis plant growth and post-anthesis grain starch biosynthesis. *J. Integr. Agric.* **2024**, *23*, 536–550. [CrossRef]
13. Li, X.; Noor, H.; Noor, F.; Ding, P.; Sun, M.; Gao, Z. Effect of Soil Water and Nutrient Uptake on Nitrogen Use Efficiency, and Yield of Winter Wheat. *Agronomy* **2024**, *14*, 819. [CrossRef]
14. Yan, S.; Wu, Y.; Fan, J.; Zhang, F.; Guo, J.; Zheng, J.; Wu, L. Optimization of drip irrigation and fertilization regimes to enhance winter wheat grain yield by improving post-anthesis dry matter accumulation and translocation in northwest China. *Agric. Water Manag.* **2022**, *271*, 107782. [CrossRef]
15. Yuan, J.Y.; Sadiq, M.; Rahim, N.; Li, G.; Yan, L.J.; Wu, J.Q.; Xu, G.R. Tillage Strategy and Nitrogen Fertilization Methods Influences on Selected Soil Quality Indicators and Spring Wheat Yield under Semi-Arid Environmental Conditions of the Loess Plateau, China. *Appl. Sci.* **2022**, *12*, 1101. [CrossRef]
16. Ma, L.; Shi, L.; Wang, S.; Wang, K.; Zheng, W.; Li, Z.; Zhai, B. 15N labelling of cattle manure reveals the distribution of organic fertiliser nitrogen in a winter wheat system. *Field Crops Res.* **2022**, *283*, 108529. [CrossRef]
17. Li, Y.; Wei, J.; Ma, L.; Wu, X.; Zheng, F.; Cui, R.; Tan, D. Enhancing Wheat Yield Through Microbial Organic Fertilizer Substitution for Partial Chemical Fertilization: Regulation of Nitrogen Conversion and Utilization. *J. Soil Sci. Plant Nutr.* **2024**, *24*, 935–943. [CrossRef]
18. Zhou, Z.K.; Zhang, S.Y.; Jiang, N.; Xiu, W.M.; Zhao, J.N.; Yang, D.L. Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Front. Environ. Sci.* **2022**, *10*, 1058071. [CrossRef]
19. Liu, P.; Guo, X.; Zhou, D.; Zhang, Q.; Ren, X.; Wang, R.; Wang, X.; Chen, X.; Li, J. Quantify the effect of manure fertilizer addition and optimal nitrogen input on rainfed wheat yield and nitrogen requirement using nitrogen nutrition index. *Agric. Ecosyst. Environ.* **2023**, *345*, 108319. [CrossRef]
20. Wang, L.L.; Li, Q.; Coulter, J.A.; Xie, J.H.; Luo, Z.Z.; Zhang, R.Z.; Deng, X.P.; Li, L.L. Winter wheat yield and water use efficiency response to organic fertilization in northern China: A meta-analysis. *Agric. Water Manag.* **2020**, *229*, 105934. [CrossRef]
21. McLeod, S. Determination of total soil and plant nitrogen using a micro-distillation unit in a continuous flow analyzer. *Anal. Chim. Acta* **1992**, *266*, 113–117. [CrossRef]
22. Noor, H.; Yan, Z.; Sun, P.; Zhang, L.; Ding, P.; Li, L.; Ren, A.; Sun, M.; Gao, Z. Effects of Nitrogen on Photosynthetic Productivity and Yield Quality of Wheat (*Triticum aestivum* L.). *Agronomy* **2023**, *13*, 1488. [CrossRef]
23. Ning, L.Y.R.; Xu, X.P.; Zhang, Y.T.; Zhao, S.C.; Qiu, S.J.; Ding, W.C.; Zou, G.Y.; He, P. Effects of chicken manure substitution for mineral nitrogen fertilizer on crop yield and soil fertility in a reduced nitrogen input regime of North-Central China. *Front. Plant Sci.* **2022**, *13*, 1050179. [CrossRef]
24. Wang, R.; Wang, H.; Jiang, G.; Liu, J.; Yin, H.; Xie, B.; Che, Z.; Jiang, F.; Zhang, T. Effect of Nitrogen Application on Root and Yield Traits of Chinese Spring Wheat (*Triticum aestivum* L.) under Drip Irrigation. *Agronomy* **2022**, *12*, 2618. [CrossRef]
25. Ye, S.; Zheng, C.; Zhang, Y.; Liu, X. Effects of reduced chemical nitrogen input combined with organic fertilizer application on the productivity of winter wheat and summer maize rotation and soil properties in central Henan Province. *Chin. J. Eco-Agric.* **2022**, *30*, 900–912. [CrossRef]
26. Brunel, N.; Seguel, O.; Acevedo, E. Conservation tillage and water availability for wheat in the dryland of central chile. *J. Soil Sci. Plant Nutr.* **2013**, *13*, 622–637. [CrossRef]
27. Rempelos, L.; Wang, J.; Sufar, E.K.; Almuayrifi, M.S.B.; Knutt, D.; Leifert, H.; Leifert, A.; Wilkinson, A.; Shotton, P.; Hasanaliyeva, G.; et al. Breeding Bread-Making Wheat Varieties for Organic Farming Systems: The Need to Target Productivity, Robustness, Resource Use Efficiency and Grain Quality Traits. *Foods* **2023**, *12*, 1209. [CrossRef] [PubMed]

28. Lv, M.; Huang, M.; Zhao, K.N.; Gu, X.X.; Li, S.Q.; Wang, J.T.; Yin, F.; Liu, L.; Jiao, N.Y.; Fu, G.Z. Effects of Partial Substitution of Organic Fertilizer for Synthetic N Fertilizer on Yield and N Use Efficiencies in a Semiarid Winter Wheat-Summer Maize Rotation. *Agronomy* **2023**, *13*, 2281. [CrossRef]
29. Li, Z.; Cui, S.; Zhang, Q.P.; Xu, G.; Feng, Q.S.; Chen, C.; Li, Y. Optimizing Wheat Yield, Water, and Nitrogen Use Efficiency With Water and Nitrogen Inputs in China: A Synthesis and Life Cycle Assessment. *Front. Plant Sci.* **2022**, *13*, 930484. [CrossRef]
30. Alharbi, S.; Majrashi, A.; Ghoneim, A.M.; Ali, E.F.; Modahish, A.S.; Hassan, F.A.S.; Eissa, M.A. A New Method to Recycle DairyWaste for the Nutrition of Wheat Plants. *Agronomy* **2021**, *11*, 840. [CrossRef]
31. Bulut, S.; Öztürk, A.; Karaoglu, M.M.; Yildiz, N. Effects of organic manures and non-chemical weed control on wheat. II. Grain quality. *Turk. J. Agric. For.* **2013**, *37*, 271–280. [CrossRef]
32. Rehim, A.; Khan, M.; Imran, M.; Bashir, M.A.; Ul-Allah, S.; Khan, M.N.; Hussain, M. Integrated use of farm manure and synthetic nitrogen fertilizer improves nitrogen use efficiency, yield and grain quality in wheat. *Ital. J. Agron.* **2020**, *15*, 29–34. [CrossRef]
33. Mayer, J.; Gunst, L.; Mäder, P.; Samson, M.-F.; Carcea, M.; Narducci, V.; Thomsen, I.K.; Dubois, D. Productivity, quality and sustainability of winter wheat under long-term conventional and organic management in Switzerland. *Eur. J. Agron.* **2015**, *65*, 27–39. [CrossRef]
34. Mulè, P.; Dettori, M.; Carboni, G. Effect of Animal ByProducts Fertilization on Durum Wheat in Mediterranean Conditions: Preliminary Results. *Plants* **2020**, *9*, 1094. [CrossRef]
35. Lin, Z.; Chang, X.H.; Wang, D.M.; Zhao, G.C.; Zhao, B.Q. Long-term fertilization effects on processing quality of wheat grain in the North China Plain. *Field Crops Res.* **2015**, *174*, 55–60. [CrossRef]
36. Si, Z.Y.; Qin, A.Z.; Liang, Y.P.; Duan, A.W.; Gao, Y. A Review on Regulation of Irrigation Management on Wheat Physiology, Grain Yield, and Quality. *Plants* **2023**, *12*, 692. [CrossRef]