Assessment of farmers' water and fertilizer practices and perceptions in the North China Plain

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Abstract
Irrigation and fertilization are vital to increasing crop yield, but their application often exceeds crop requirements. Excessive fertilization under inefficient irrigation depletes the already scarce water resources while contributing to water pollution. To overcome these problems, the introduction of fertigation in combination with modern irrigation technologies has been promoted in the North China Plain (NCP), but farmers have been reluctant to adopt such technologies. To better understand the current situation and farmers' perceptions, we performed a case study in the People's Victory Canal Irrigation District (PVCID) of NCP. A field survey was carried out using a participatory approach, and field monitoring was conducted on a representative farm. We found that farmers are generally satisfied with their irrigation and fertilization practices, although they result in low application efficiency and distribution uniformity. In principle, the lack of knowledge about how to implement fertigation technology, the small-scale farming conditions, and the high cost of developing advanced fertigation systems are the main obstacles for fertigation adoption. We further conclude that (i) to improve the on-farm performance in terms of efficiency and uniformity of irrigation and fertilization, evidence-based guidelines are required to help farmers to implement; (ii) for effective adoption of new technologies, consideration of farmers' situation and perspectives is critical; and (iii) surface fertigation might be a good start for fertigation promotion.

KEYWORDS
surface irrigation, fertigation, participatory approach, field monitoring

Résumé
L'irrigation et la fertilisation sont essentielles pour augmenter le rendement des cultures, mais leur application dépasse souvent les besoins des cultures. La fertilisation excessive dans le cadre d'une irrigation inefficace épuise les...
ressources déjà limitées en eau tout en contribuant à la pollution de l'eau. Pour surmonter ces problèmes, l'introduction de la fertilisation en combinaison avec des technologies d'irrigation modernes a été encouragée dans la plaine du nord de la Chine, mais les agriculteurs ont été réticents à adopter de telles technologies. Pour mieux comprendre la situation actuelle et les perceptions des agriculteurs, nous avons réalisé une étude de cas dans le District d'irrigation du Canal de la victoire du peuple (PVCID) du NCP. Une enquête sur le terrain a été menée selon une approche participative et une surveillance des champs a été effectuée sur une exploitation représentative. Nous avons constaté que les agriculteurs sont généralement satisfaits de leurs pratiques d'irrigation et de fertilisation, bien qu'elles entraînent une faible efficacité d'application et une distribution uniforme. En principe, le manque de connaissances pour mettre en œuvre la technologie de fertigation, les conditions agricoles à petite échelle et le coût élevé du développement de systèmes avancés de fertigation sont les principaux obstacles à l'adoption de la fertigation. Nous concluons en outre que (i) pour améliorer les performances de l'exploitation en termes d'efficacité et d'uniformité de l'irrigation et de la fertilisation, des lignes directrices fondées sur les preuves sont nécessaires pour aider les agriculteurs à mettre en œuvre; (ii) pour une adoption efficace des nouvelles technologies, il est essentiel de tenir compte de la situation et des perspectives des agriculteurs; III) la fertigation des surfaces pourrait être un bon début pour la promotion de la fertilisation.

MOTS CLÉS
irrigation de surface, fertigation, approche participative, surveillance des champs

1 | INTRODUCTION

Irrigation and fertilization significantly affect crop yield and are vital to grain production and food security (De Fraiture et al., 2014; Mueller et al., 2012; Zhang et al., 2015). Irrigated agriculture accounts for approximately 20% of the world’s arable land and is estimated to yield 40% of crop production (FAO, 2017). In addition to water supply, a reliable nitrogen supply is another essential factor that has allowed farmers to significantly increase crop yields over the past decades (Sutton, 2013). However, conventional surface irrigation systems often result in inefficient water and fertilizer use and increase the risk of nonpoint pollution (Fan et al., 2014; Lockhart et al., 2013; Quemada et al., 2013). Thus, it is essential to improve on-farm irrigation and fertilization practices and techniques.

Pressurized fertigation methods, such as drip fertigation and sprinkler fertigation, are highly recommended for enhancing resource use efficiency and mitigating the pollution of surface water and groundwater (Chojnacka et al., 2020). Fertigation is an agronomic technique by which water and fertilizer are supplied simultaneously (Hagin & Lowengart, 1996). It is intended to be a way for growing crops using less fertilizer, better water and nutrient use efficiency, and labour savings. The use of fertigation can lower production costs while bringing opportunities for improved crop yields (Kabirigi et al., 2017). As surface irrigation is the dominant practice in most irrigated areas (Liu, Wang, et al., 2020; Siebert et al., 2005), many efforts have been made to promote pressurized irrigation in the fields (Gupta et al., 2021; Lecina et al., 2010; Yao et al., 2017).

The North China Plain (NCP), one of China’s most densely populated regions, is intensively farmed to produce enough food to feed the large population (Dalin et al., 2015; Du et al., 2013). Therefore, the farming system has highly relied on irrigation and fertilization practices (Li, Wen, et al., 2020; Ju et al., 2006). Agriculture here accounts for more than 60% of the total water use, although the irrigation efficiency is not high (China, 2017). The nitrogen application rate is also high, at approximately 305 kg/ha annually, compared to the world average of 74 kg/ha/year (Cui et al., 2018). Most
fertilizer leaches away from the plant root zone, contributing to nonpoint pollution (Fang et al., 2006; Li et al., 2016). Water stress in the region has increased over the past years due to intensive farming and inefficient irrigation (Deng et al., 2021). In addition to the growing water stress problem, fertilizer overuse is also a concern (Cui et al., 2010). When water supplies are limited, farmers add fertilizers to compensate. However, fertilizer overapplication depletes soil moisture and increases plant water consumption (Liu et al., 2015). Excessive fertilization with inefficient irrigation has diminished the region’s already scarce water resources and increased nitrogen pollution (Liu et al., 2019).

China’s Ministry of Agriculture and Rural Affairs (MARA) has therefore promoted “fertigation” technologies since 2012 (Gao, Du, et al., 2015). Drip fertigation, which integrates well with micro-irrigation practices, has been extended to dryland areas in China’s northwest regions (Li et al., 2021). Furthermore, research suggested that the use of drip fertigation could enable northern China to better manage water supplies and soil nutrients (Bai et al., 2020). It is, however, difficult to introduce these advanced irrigation methods across the whole NCP because they require significant investments for both construction and maintenance, which are unaffordable for the region’s farmers (Chen & Whalen, 2016). Moreover, the water in this region, particularly that from the Yellow River, is rich in sediment, limiting pressurized irrigation systems (Miao et al., 2015). Subsequently, 86% of the cultivated lands were still irrigated using surface systems (Chen, 2017).

Although agricultural agencies have sought ways to reduce fertilizer and water usage, NCP farmers have resisted adopting new fertigation practices. Compared to current practices, advanced fertigation systems require more significant investment in construction and operation, such as specific equipment to implement (Yang et al., 2021). In addition, investing in a new system is a complex decision. Many factors play a role, such as system adequacy, profitability, predictability, and convenience (Zhang et al., 2019). Over time, farmers experimented with irrigation and fertilizer application practices, ultimately choosing the dominant mode, mainly due to the low cost and ease of crop management (Tang et al., 2016). Farmers remain unconvinced that modern technology can truly lead to higher benefits (Zhang et al., 2016). They are therefore reluctant to believe in the potential benefits of more efficient fertigation techniques.

Compared with the aspirational promotion of fertigation by governmental agencies, there is a general lack of research analysing farmers’ adoption challenges. Additionally, it is necessary to consider farmers’ attitudes and perceptions of their current farming practices to boost the acceptance of new technologies. This was the goal of the current research. Specifically, this study had three main aims: (i) to assess existing irrigation and fertigation practices in farmers’ fields, (ii) to provide insights into farmers’ perception of their current practices, and (iii) to address the challenges of fertigation adoption in farmers’ fields.

2 | MATERIALS AND METHODS

2.1 | The case study area

Our case study focused on the People’s Victory Canal Irrigation District (PVCID), which is in the southern NCP (113°30’–114°5’ E, 35°–35°20’ N; Figure 1) and covers 99,000 ha. This is a significant and traditional agricultural region of China and a key area for producing winter wheat and summer maize. Farming practices here are representative of the intensive agriculture found throughout the NCP. Soils in the PVCID are mainly sandy loam, and most irrigation water is provided by groundwater or the Yellow River (Dai, Zhang, Han, et al., 2017). Annual precipitation ranges from 365 to 886 mm, with most rain-fall occurring in summer, from June to August (Chang et al., 2017).

The research included a field survey across the whole PVCID district from October 2017 to February 2018 and a field monitoring programme centred on the midstream of the district from October 2017 until June 2019.

2.2 | Methodology

Local farmers can constitute a valuable knowledge source (Ritzema et al., 2010) for rural appraisal. As little data were available about the assessment of current agricultural practices in the farmers’ fields, we chose a participatory approach to evaluate the current situation using local farmers’ knowledge. Participatory rural appraisal (PRA) is a term used to describe a growing range of methods that can encourage stakeholders to analyse, evaluate, and bring their knowledge to the process (Chambers, 1994; Friday et al., 2011). Figure 2 presents our study’s methodological design, which comprises three phases: (1) a field observation to verify what farmers do, (2) a survey among farmers to determine what farmers say, and (3) matching the field assessment and farmers’ perception to draw the lessons learned.
2.2.1 Participatory rural appraisal

The farmer survey aimed to better understand the current situation in the study district, particularly to identify the farmers' concerns and the challenges they faced in the fields. We began our survey by contacting the PVCID administrative headquarters to select three district offices, one upstream, one midstream, and one downstream. We interviewed water management staff in the three branch offices and then asked them to guide us to the field for semi-structured interviews with farmers. The discussions began by eliciting information on the irrigation area, water demand and supply, and crop patterns. This was followed by asking more detailed data on irrigation and fertilization practices, such as irrigation and fertilization methods, irrigation system layouts, and soil conditions. Based on these interview findings, we designed a questionnaire for farmers in the study area.

Our questionnaire survey zoomed in on 10 randomly selected communities evenly distributed from upstream to downstream. The questionnaires explored farming practices and farmers' attitudes regarding irrigation and fertilization, which were administered to 31 random households. Data were collected on the number of farming plots, average plot size, frequencies of irrigation and fertilization, quantities of water and fertilizer used, crop

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**FIGURE 1** Study area in the People’s Victory Canal Irrigation District of North China Plain

**FIGURE 2** Flow chart presenting the study’s methodological design
yields and farming costs, among other things. To analyse the current fertilization habits and explore farmers’ fertilizer use decisions, we also interviewed three fertilizer retailers by querying fertilization schedule, purchasing behaviour, fertilizer price, information sources, and soil fertility.

2.2.2 | Monitoring farmers’ fields

For our field observations, we strategically selected a plot representing the average plot size and soil quality in the study area. We began with transect walks to better understand the current irrigation infrastructure and practices. The groundwater table here is approximately 10 m deep, and the soil is mainly loam. After this preliminary investigation, we carried out participatory field monitoring to collect the needed data for irrigation and fertilization performance calculations. The representative plot was farmed by a local farmer who was asked to conduct her activities as usual, with us simply observing and recording her irrigation and fertilization practices.

We sketched the monitoring field’s layout (247 m in length, with 2.1 m width, and an average slope of 0.24%) and confirmed the accuracy of the drawing with the local farmer. There was a cement channel for irrigation at the head of the plot, and irrigation water was pumped in from a nearby well. The plot was irrigated by using the border irrigation method. In total, five irrigation events, including two fertilizer topdressings, were monitored during the wheat growing season in 2018 and 2019. For each irrigation event, we measured data on inflow rate, advance and recession (A&R) time, as well as soil moisture and nitrogen content (detailed records in Table 1).

The inflow rate was measured using the U-shaped channel calculation method. The A&R time was recorded manually by observing the water advancement every 20 m along the border during irrigation. The soil water and nitrogen contents were measured 1 day before irrigation and 2 days as well as 7 days after irrigation. Sampling points were located 10, 50, 100, 150, and 190 m away from the head of the field, and soil samples were collected every 20 cm from the surface to a depth of 2 m (the maximum rooting depth of wheat and maize) using a soil auger. Every soil sample was split into two parts, and one was used to calculate gravimetric moisture by the oven-drying method. The remaining part was used to analyse the soil nitrate and ammonium contents by using an automatic discrete analyser (CleverChem Anna, DeChem-Tech, Germany) in the laboratory. The data from the monitoring measurements were used to analyse the on-farm irrigation and fertilization performance.

2.2.3 | Modelling assessment

To assess the on-farm performance of current irrigation practices, we used the software package WinSRFR (USDA-ARS Arid-Land Agricultural Research Center), a hydraulic analysis tool for surface irrigation that combines simulation, evaluation, operational analysis, and design functionalities (Bautista et al., 2016). We selected WinSRFR because it is open access and has proven its capability to assess the efficiency of border irrigation practices (Salahou et al., 2018).

In the model, the empirical Kostiakov infiltration equation was applied, which is the most widely used function for surface irrigation:

\[ I = KT^\alpha \] (1)

### Table 1: Irrigation data collected in the monitoring field

| Date         | Inflow rate (m³/hr) | Irrigation time (min) | Irrigation amount (mm) | Fertilization (kg/ha) | Soil samples | Advance and recession time |
|--------------|---------------------|-----------------------|------------------------|-----------------------|--------------|---------------------------|
| December 30, 2017 | 40                  | 112                   | 143                    |                       | Before irrigation | Both                      |
| March 8, 2018       | 40                  | 118                   | 152                    | 225 (urea)            | Before and after irrigation | Both                      |
| March 5, 2019       | 46                  | 128                   | 189                    | 225 (urea)            | Before and after irrigation | Advance                   |
| April 16, 2019      | 46                  | 98                    | 145                    |                       | Before and after irrigation | Both                      |
| May 15, 2019        | 46                  | 93                    | 137                    |                       | Before and after irrigation | Both                      |
| Average            | 44                  | 110                   | 153                    | 225                   | –             | –                         |
where \( I \) is the cumulative depth of infiltration (mm), \( K \) is the fitted coefficient parameter (mm/hr), \( T \) is the infiltration time (min), and \( a \) is the fitted exponent parameter.

The model used the following irrigation performance indicators (Burt et al., 1997; Mazarei et al., 2021):

\[
AE = \frac{\text{volume of water added to the root zone}}{\text{total volume of water applied}},
\]

\[
\text{DU}_{\text{iq}} = \frac{\text{average of the lowest 25% of applied irrigation depths}}{\text{average applied irrigation depth in the whole field}},
\]

and

\[
\text{DP} = \frac{\text{average depth of water drained beyond the root zone}}{\text{total volume of water applied}},
\]

where \( AE \) is the application efficiency, \( \text{DU}_{\text{iq}} \) is the distribution uniformity, and \( \text{DP} \) is the deep percolation, all expressed as percentages.

The model was calibrated and validated with data measured for five irrigation events during the winter wheat seasons of 2018 and 2019 (see Table 1). First, we input the data from the field survey regarding field layout, irrigation method, and irrigation requirement. Second, we set the initial crop and soil parameters based on another study from a nearby site (Wang, 2018). Third, we applied the trial-and-error method to calibrate the parameters by comparing the simulated A&R time with measured values. To evaluate model accuracy, we compared the simulated A&R time with field measurements using the following statistical parameters: coefficient of determination \( (R^2) \), Nash–Sutcliffe efficiency (NSE), and root mean square error (RMSE) (Krause et al., 2005; Moriasi et al., 2007).

\[
R^2 = \left( \frac{\sum_{i=1}^{n} (O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n} (O_i - \bar{O})^2 \sqrt{\sum_{i=1}^{n} (S_i - \bar{S})^2}}} \right)^2,
\]

\[
\text{NSE} = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \text{, and}
\]

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (S_i - O_i)^2},
\]

where \( O_i \) is the \( i \)th observation for the constituent being evaluated, and \( S_i \) is the \( i \)th simulated value for the constituent being evaluated. \( \bar{O} \) is the average of observed data for the constituent being evaluated, \( \bar{S} \) is the average of simulated data for the constituent being assessed, and \( n \) is the total number of observations.

To analyse fertilization performance in the field, we used Surfer, a programme for analysing and visualizing 3D data (www.goldensoftware.com). This enabled us to gain insight into how soil nitrate and ammonium nitrogen were distributed using the data collected in the field monitoring phase.

### 3 | RESULTS

#### 3.1 | Appraisal of farmers’ dominant water and fertilizer practices

The cropping pattern most common in this region was a winter wheat–summer maize rotation (Figure 3). Additionally, some wheat–rice fields were found upstream due to easy access to Yellow River water. Notwithstanding the few rice fields, most farmers in the study area preferred the wheat–maize rotation because of the easy farming management and access to water sources. As observed in the crop calendar (Figure 3), there was no fallow period during the year. The soils were left uncultivated only 2 weeks after the maize harvest. Early October was the best time to sow winter wheat and harvest in early June (Liang et al., 2019). Before wheat planting, the lands were ploughed and harrowed, and compound fertilizer (approximately 20% N and 50% P) was applied in a range of 600–900 kg/ha. Additionally, farmers applied 150–375 kg/ha of urea (46% N) in spring as topdressing by broadcasting the fertilizer on the soil immediately before the irrigation was carried out. After wheat harvest and simple land preparation, summer maize was planted with compound fertilizer application at 600–900 kg/ha again in mid-June. Three months later, the maize was harvested as the seasonal growth period was short. We found broadly similar farming practices among farmers using river water and those using groundwater for irrigation. All farmers expressed a preference for border irrigation systems and fertilization application by a broadcast method.

The farmers had developed irrigation strategies geared to limit the risk of crop failure and minimize production costs. Two to four irrigation applications were typically applied in farmers’ fields in the wheat season (see Figure 3). The first irrigation application took place...
in winter to limit frost damage. The second application was in early March, in tandem with nitrogen fertilization to promote wheat crop development. Farmers applied urea with the second irrigation for easy nitrogen absorption during the green-up stage. They sometimes combined these first two irrigation applications into one in late February or early March for the fertilizer application. The third and fourth irrigation applications were in April and May, respectively, at the grain-filling and maturity stages of the wheat crop. Irrigation at these points was an effective way to boost yields, as farmers said. If there is sufficient rainfall, these two irrigations could be reduced to one, often in mid-April. For summer maize, farmers generally do not irrigate their lands, as the rain was intensive in this season. However, they sometimes applied irrigation once or twice after sowing if precipitation was insufficient. Additionally, no additional fertilizer was applied after maize planting because of the difficulty of broadcasting fertilizer in the field. Farmers said they were unlikely to fertilize summer maize after sowing because the crop is tall with long leaves, making it difficult to broadcast fertilizer in the field. Moreover, the tall

**FIGURE 3** Crop calendar for the winter wheat–summer maize rotation in the study area

**FIGURE 4** Measured and simulated advance and recession times. NSE, Nash–Sutcliffe efficiency; $R^2$, coefficient of determination; RMSE, root mean square error
TABLE 2  Evaluation of irrigation performance using WinSRFR

| Date        | AE (%) | DU (%) | DP (%) | DP (mm) |
|-------------|--------|--------|--------|---------|
| December 30, 2017 | 63     | 93     | 37     | 53      |
| March 8, 2018    | 59     | 85     | 41     | 62      |
| March 5, 2019    | 48     | 91     | 53     | 100     |
| April 16, 2019   | 62     | 96     | 38     | 55      |
| May 15, 2019     | 65     | 84     | 35     | 48      |
| Average         | 59     | 90     | 41     | 64      |

Abbreviations: AE, application efficiency; DU, distribution uniformity; DP, deep percolation.

FIGURE 5  Soil water content change before and after irrigation

a. Average soil moisture of every soil layer along the border

b. Average soil moisture at each sampling point
crop made the fields swelter, so farmers were reluctant to enter them. What they usually did was fertilize once with a massive amount of chemical fertilizer before sowing.

Table 1 shows the detailed records of the five irrigation events at the monitoring field. We applied the data from the monitored events to analyze irrigation performance by WinSRFR in terms of AE and DU.

We used the measured A&R time to calibrate the model. Figure 4 shows the performance of the simulation results, from which we can see a good fit between the measured and simulated times along the 1:1 line. The statistical indicators calculated and displayed in the figure present the good performance of the model. The correlation was found to be very high, within the 0.91–1.00 range. From the statistical results, we concluded that the model was well calibrated and validated for the study. Additionally, the estimated infiltration parameters of K and α for each irrigation event were calculated. They were on the same order of magnitude (80 ≤ K ≤ 120, 0.4 ≤ α ≤ 0.6) as those found in the literature (Bautista et al., 2016; Wang, 2018), which further supports our finding and model validation.

The calibrated and validated WinSRFR model was then used to estimate irrigation performance (Table 2). The irrigation was satisfied, as all irrigation amounts met the required depth of 90 mm (the usual depth of irrigation applied in the area). The irrigation application efficiency ranged from 48% to 65%, and the distribution uniformity was relatively high, ranging from 84% to 96%. Deep percolation went from 48 to 62 mm, except on March 5, 2019, when the deep percolation was extremely high (100 mm). That day’s irrigation amount (I = 189 mm) was far greater than those for the other irrigation events (range 137–152 mm). These results indicated that the farmer’s control of operation was unstable and baseless, and the irrigation duration was sometimes long due to inappropriate cut-off choices.

Figure 5 displays the spatial distribution pattern of the change in soil moisture resulting from the irrigation events of March 5 and May 15, 2019. The statistics show that following the irrigation event of March 5, 2019 (no rain recorded), the soil moisture at the bottom end of the border was high (Figure 5), indicating that over-irrigation occurred. This explains the high DP (100 mm) and low AE (48%) for this irrigation event.

The figures also indicate that farmers overirrigate their field in winter. At a nearby experimental site, field capacity (FC) was reported as an average of 24% (Gao, Shen, et al., 2015). In our case, the topsoil (0–30 cm) moisture after irrigation was higher than the FC, especially at the end of the border. Thus, the irrigation water applied to the field indeed appears to be excessive, leading to percolation that is much higher than the leaching requirements. Percolation water losses can result in chemical leaching, causing deep soil and groundwater contamination (Liu et al., 2013).

It was not only the excessive rate of water usage that increased the risk of nitrogen pollution but also the farmers’ method of fertilizer application led to nitrogen leaching via water percolation. Measurements demonstrated this in the monitoring field. On the field plot, the farmer applied 225 kg/ha synthetic urea (N > 46%) by the broadcast method immediately before the irrigation event on the same day. The nitrate and ammonium nitrogen contents changed significantly after irrigation and fertilization (Figure 6). Here, we noted that the nitrogen accumulated at the end of the border rather than being uniformly distributed throughout the field or concentrated elsewhere along the border. This was likely due to high inflow rates that flushed the broadcast fertilizer to the field’s bottom end. Regardless of whether the urea was spread onto the soil surface uniformly or non-uniformly, once irrigation waters entered the field, the particles flowed with the water from the head to the bottom end of the border, especially when the inflow rate was high. This points to a risk of leaching at the end of the border, especially on long borders where substantial quantities of water accumulate at the end (Cui et al., 2006; Liu, Wang, et al., 2020).

3.2 Farmers’ perception of current practices

Almost all the farmers relied mainly on border irrigation, which they found to be a simple method that did not require sophisticated equipment and management. Usually, farmers considered a field to be well irrigated as long as the water reached the bottom end of the border. This meant that, in most irrigation applications, the end of the border could be overwatered, resulting in a high risk of water and fertilizer loss via deep percolation. However, most of the farmers surveyed were unaware of the problems caused by unreasonable irrigation practices due to baseless cut-off times. They were under the impression that their current irrigation method was easy to operate and beneficial, resulting in stable crop production.

Because of these recognized shortcomings of the irrigation systems used in the study area, the local government has promoted more advanced irrigation methods, such as a sprinkler system. However, only 25% of the interviewed farmers indicated a willingness to switch from their current irrigation method. The remaining farmers expressed doubt about whether their conventional irrigation system actually wasted water and whether new irrigation methods would bring increased
benefits. They also expressed fear of high investment costs for the construction and maintenance of more advanced irrigation systems.

Broadcast fertilization with border irrigation was the dominant management practice in the study region. We expected soil fertility to affect fertilizer use practices. However, we found that the amount of fertilizer applied did not, in fact, depend on how fertile the soil was. We found that the surveyed farmers’ beliefs and preferences regarding fertilizer practices hinged on three factors: personal experience, ease of handling, and application cost.

Table 3 shows the fertilization practices recorded by the local farmers.

The main fertilizer used at seeding was compound fertilizer (nitrogen, phosphorus, and potassium) or diammonium phosphate, and the main topdressing fertilizer was urea. Most of the interviewed farmers (90%) agreed that they had contributed to an overall increase in fertilizer use over the years. Among these interviews, some comments indicated that they were aware of problems linked to the overuse of chemical fertilizers. However, that awareness did not necessarily translate into a desire
to cut chemical fertilizer use, as can be read in the following quotes:

For the topdressing urea, I used to put just 10 Jin per mu [75 kg/ha] in my fields 30 years ago. Today, I used 30 Jin per mu [225 kg/ha].

I tend to use chemical fertilizers rather than the organic fertilizers I used 17 years ago. I do have a sense that too much fertilizer can cause soil depletion. However, I’m not going to reduce fertilizer use in case of crop failure.

Only 17% of the surveyed farmers expressed a willingness to reduce their fertilizer application rates. As nitrogen fertilizer use, in particular, has been found to be relatively high compared to the recommended dosage (168 kg/ha for maize and 151 kg/ha for wheat), studies suggest that organic fertilizers are necessary for sustainable development (Yin et al., 2021). However, the fertilizer retailers interviewed for the current research considered it impossible to produce enough crops using only organic fertilizers such as manure. Farmers also noted that chemical fertilizers gave their crops an immediate supply of nutrients. They further told us that organic fertilizers were challenging to obtain in the quantities required to meet crop needs. Moreover, they observed that more work was required to apply the same nutrients using organic fertilizers than chemical fertilizers. The decision to use chemical fertilizers was based on these being easier to apply than organic fertilizers.

In addition to high nutrient content, price was another factor in farmers’ fertilizer selection. They reported that organic fertilizers were usually more expensive than inorganic varieties. The fertilizer retailers said that an indirect subsidy from the government was provided to fertilizer producers, which stimulated the surplus production of synthetic fertilizers and reduced the price.

3.3 Farmers’ challenges in technology updating

Farmers already knew about the option of applying fertilizers in irrigation water (fertigation), as the local government had promoted sprinkler and drip fertigation on demonstration sites. However, the implementation of pressurized fertigation has proven complicated for farmers, so they have not embraced the new technology (Yang et al., 2021). On the one hand, fertigation adoption requires greater awareness and knowledge among farmers. On the other hand, its application requires more consideration of the water source, irrigation scheduling, and operation timing. The farmers who did indicate a willingness to adopt new technologies were motivated, particularly by the prospect of yield sustainability and ease of management.

It was found that increased farm size can lead to reduced fertilizer use, and the chance for adopting advanced technology may be greater on larger-scale farms (Wu et al., 2018). From our survey, however, we determined that most PVCID farmers are smallholders, as in other areas of the NCP (Tan et al., 2013). The households surveyed here had less than 1 ha of land (average 0.55 ha), divided into several plots depending on soil quality and irrigation accessibility (Table 4). Blocked borders are commonly separated plots for easy irrigation and machinery operation, and their size varies, usually in the range of 0.23–0.34 ha, with a border length of 100–300 m. Border width also varies, depending on the terrain and size of machinery used. On average, each household had two or three plots, again, depending on the quality of the soil and irrigation water availability.

In addition, most producers in this region are smallholders who earn little or no income from farming and supplement farming with other income-generating pursuits. The farmers surveyed in our research expressed little motivation to change their current practices, mainly if switching would require investment in new technologies and infrastructure. We queried the farming income of the surveyed farmers. Table 5 presents the costs of the main farming inputs: seeds, pesticides, fertilizers, machinery, and irrigation. Labour costs were omitted, as these are costs, but not expenditures as they conducted the fieldwork themselves.

Water was an inexpensive input compared to other farming costs. The primary expenditures for irrigation were the cost of electricity to pump groundwater in well-irrigated areas, and the water delivery fee paid by farmers in irrigated areas with surface water (Dai et al., 2015). The fertilizer price was relatively high, €381/ha, as the application rate was considerable, and strategic savings could significantly reduce the fertilizer costs. Although farmers sought ways to improve their yields while reducing farming costs, they also indicated an unwillingness to reduce water and fertilizer use. They considered irrigation and fertigation to be essential to ensure good yields.

We found that even if farmers were willing to adopt new technologies, they were unwilling to pay for them. Farmers gained little from their grain crops due to the fields’ high input requirements (almost 2000 €/ha/year) and the low net benefit (only approximately 2000 €/ha/year). As the existing farming systems are hardly profitable, farmers are understandably reluctant to invest in
new technologies. Thus, the persistence of small-scale farming and high investment have hindered the adoption of advanced agricultural technologies.

Some farmers are willing to adopt new technologies only if appropriate stimulus policies and subsidies are in place, such as financial support to install the fertigation system. They said that the government should provide them for free or compensate farmers for the lack of an adequate water supply. Additionally, they did not see how they could profit from making changes. This points to the importance of giving farmers opportunities to learn how much they could benefit from adopting new technology; despite the higher costs, they will save more on costs of irrigation and especially on fertilizers.

4 | DISCUSSION

Conventional border irrigation systems for wheat and maize are popular among NCP farmers, but these do consume large quantities of water. Irrigation application efficiency was low due to farmers’ poor on-farm management practices. Moreover, the broadcasting fertilization also resulted in low fertilizer uniformity in the field, although it is manoeuvrable. Our field monitoring found that the irrigation cut-off was not reasonable at times, meaning that too much water entered the field, leading to excessive percolation and leaching. This confirms that irrigation efficiency improvements could be an essential first step towards more sustainable agriculture in the region (Liu et al., 2019). For example, clear guidelines could be issued on cut-off times and inflow control, border size and slope rationalization, and land levelling (Liu, Jiao, et al., 2020). However, our study also shows that the high inflow could result in fertilizer flushing to the bottom end of the field, where it was lost via deep percolation. Thus, increasing the inflow rate for irrigation improvement could be a dilemma when considering broadcast fertilization.

In addition, our study indicates that farmers were not using fertilizers efficiently, as the amounts applied were high compared to the crop required dosage. The actual application rate was determined by recommendations made by retailers, what neighbours were doing and farmers’ own experiences. Farmers in the study area used two fertilizer applications: basal fertilization and top-dressing. The first was a compound fertilizer applied during seeding, and the second was an additional nitrogen fertilizer at the green-up stage (Figure 3). Winter wheat absorbs most of its nitrogen (35–40%) in early April and maize in July, so it is critical to have enough fertilizer available to the crop at these times (Liu et al., 2006). However, farmers usually fertilized summer maize only once upon sowing with considerable synthetic fertilizer. This likely led to nitrogen leaching, reducing nitrogen use efficiency as rainfall was highly concentrated during the maize growing season (Jia et al., 2014). Some studies also point out different factors that can influence farmers’ decisions on fertilizer use (Han & Zhao, 2009). For example, institutional support for soil testing plays a role since
farmer's perception of fertigation adoption.

5 | CONCLUSION

This study used a PRA and on-site field assessments to explore the performance of current surface irrigation and fertilization practices and farmers’ perceptions of these practices. We also explored farmers’ views on the adoption of new technologies, such as fertigation technology. Our field measurements demonstrated that irrigation application efficiency was relatively low (average 59%), although distribution uniformity was reasonable (average 90%). However, the fertilizer application was nonuniform along the field. All indicate water and fertilizer losses via deep percolation under the current irrigation and fertilization management practices.

Farmers, however, expressed the belief that their current management practices were acceptable because with them, crop yield could be guaranteed, and they did not cost that much. In addition, most of the farmers in our survey expressed little interest in new technologies for improving water and fertilizer use. This study also revealed that farmers’ present water and fertilizer
management methods need to be considered in any initiatives to promote wider adoption of fertigation. Identifying farmers’ needs and priorities regarding irrigation and fertilization practices is essential before advancing new technology.

To motivate farmers to make the switch, it will be essential to gain farmers’ confidence in the new technologies on offer, for example, by providing evidence-based guidelines on optimal water and fertilizer application rates, timing and other management aspects, as well as expected crop yields. Farmers need to be mentored as they switch away from their current irrigation and fertilization practices.

This research shows that it is important to start from farmers’ current practices as a first step in promoting new technology. The introduction of surface fertigation techniques could be a way to bridge the transition from current practices to more advanced fertigation practices. However, there was no extension as yet or even a pilot project to demonstrate this technique in the study area. Future research is, therefore, recommended to evaluate the surface fertigation technique in farmers’ fields.

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DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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