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Wheat Yield Gap Assessment in Using the Comparative Performance Analysis (CPA)

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Abstract: One of the crucial issues in developing nations is diminishing the yield gaps. Therefore, accurate yield gap estimation has many real-world uses for increasing crop production. Utilizing comparative performance analysis (CPA) techniques, the yield gap of wheat fields was evaluated in this study. In Varamin, Tehran Province, Iran, data on 104 wheat fields were collected between 2018 and 2020 and every aspect of wheat field management has been documented. The CPA model determines the yield gap's contributing factors and potential yield. The results of data analysis revealed that the production ranged from 2600 to 7600 kg ha^{-1}. The CPA method predicted a potential yield of 9316 kg ha^{-1} and found a yield gap of 3748 kg ha^{-1}; this amount was 40.23% of the potential yield. Leaf chlorophyll (29%), irrigation at stem extension (9%), LAI (7.7%), soil salinity (8.2%), field area (16.3%), phosphorus consumption (6%), nitrogen utilized at the stage of tillering (16%), and HI (7.8%) all contributed to the yield gap in the CPA. It has been said that the computed yield in CPA is a potential yield that can be reached. CPA is a cheap and straightforward tool that could identify yield gaps and their causes in a district without the need for costly experiments. Therefore, developing nations with significant efficiency and yield gaps can use these techniques effectively.

Keywords: field management; food security; stepwise selection; yield estimation

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1. Introduction

In agronomy, stepwise selection is commonly employed, for instance in the yield gap analysis method. By 2050, the world's population is projected to grow significantly, necessitating massive improvements in food production and food waste reduction [1,2]. Guilpart et al. claim that one of the key methods for achieving food security is to raise yield levels [3]. Assuring global food security, while also protecting the environment, may be the greatest scientific challenge currently confronting humanity [4]. The increase in the use of chemical inputs and the environmental risks they pose, together with the reduction of high-quality fields and annual crop production, suggested that a novel approach was needed to improve crop performance while posing fewer environmental risks and pollutants [5]. To meet the demand for food globally, crop performance must therefore be increased [5]. Iran, which has a population of more than 80 million, is geographically connected to the Middle East, a food-insecure zone. Iran is known for its rapid population expansion, irregular and poor rainfall, little amount of agricultural land, and scarce supply of fresh water [6]. A significant difficulty is providing enough food for the people, especially given that the use of water and land resources already has gone beyond what is sustainable [7]. In 2022, Iran produced 19.5 million tons of cereal and imported 18.3 million tons. As a result, the total consumed cereal in Iran was 37.8 million tons. More specifically, Iran produced 13 million tons of wheat during the 2022 crop year and imported 5 million tons of wheat during that same year [8].

According to a different study by Gaydon et al. [9], research studies into alternative agricultural techniques were being sparked by a lack of resources needed to boost food production while maintaining environmental sustainability. In this regard, increasing sustainable yield will require the use of a variety of techniques that are suitable for certain agroecological situations, field management techniques, and yield loss factors [10]. The results of various studies suggest that reducing the yield gap in crops is the key to meeting the rising food demand [11–15]. Plant breeding and new agronomic techniques increase potential production [10], while the yield gap closes as known advances are adopted more quickly than new ones developed [16]. The yield gap is the difference between what farmers produce and what would be possible with good cultural management [15–17].

Additionally, the yield gap calculation offers a quantitative forecast for increasing production capacity, a critical component of the regional, national, and international food security model [18]. A crop plant at full maturity yields the most when given the best water and nutrients and this is termed the potential yield [6,15,17].

Studies on food security are becoming more prevalent today, especially in Iran. It is important to utilize appropriate statistical approaches to anticipate yield gaps and identify the key barriers to achieving potential yields [6]. In this regard, there are various techniques for studying yield gaps; one of these techniques is comparative performance analysis (CPA). It can predict potential yield and yield gap causes. The primary constraint for yield and quantized functions were established for the yield gap in the CPA using multiple regressions and the stepwise technique [19]. These methods can show the connection between the variables and the simultaneous and final effects of their interaction on yield. Otherwise, estimates of potential yield may fall below their bound because regression models display an average of data scattering [19]. The usage of averages is appropriate, however, when the same management is utilized to obtain functions. Therefore, it might be important to assess the potential yield and determine its limiting factors using suitable statistical techniques.

Using the CPA method, studies have been reported in different regions of Iran [20–23] but no study with this method had been done on wheat in the studied site. However, this approach has been applied more frequently globally in conjunction with yield estimation and soil variables such as nutrient content, organic matter and acidity [10,24–27]. Estimating the potential yield and determining the minimum inputs to achieve the potential yield were less frequently used, despite the fact that the relationship between yield and precipitation, evaporation, transpiration, application of nitrogen, pests, diseases, and plant density have also been studied separately [28–31]. Additionally, simulation models may be employed for this objective [32,33]. Identification of the potential, scope, and individual performance-impacting effects of each limiting factor are crucial for determining different tactics to get the best output. The yield gap in the northern part of China ranged from 7 to 69% of the possible yield, but in a sizeable portion of the North China Plain (NCP), it was between 20 and 50%. The potential to boost wheat production was higher in the humid southern region of NCP due to higher yield gaps [34]. Pradhan [35] investigated the variables affecting the yield gap of maize and discovered that the most significant variables causing a decrease in the yield of maize were soil with a light texture, studied field area, the number of seeds planted per area, and the absence of thinning operations. These variables had shares of yield gaps of 27, 30, 30, and 13 percent, respectively.

The purpose of this study was to evaluate the wheat yield gap using CPA, based on the field management techniques of local wheat fields.

2. Materials and Methods

In Iran, wheat is planted all around the country's fields with a wide range of planting dates, according to different climates. In Varamin, it is common to plant in autumn to gain a good yield. Therefore, this research was conducted for the fall planting season. From 2018 to 2020, the research was conducted on 104 monitored wheat fields over an area of roughly 809 hectares in Pakdasht, Varamin, Tehran Province, Iran. The geographical region of 35° and 7′ to 35° and 39′ northern latitude and 51° and 26′ to 51° and 55′ eastern longitude includes the Pakdasht in Varamin plain catchment area [36], which covers more than 610 km^2 (Figure 1).

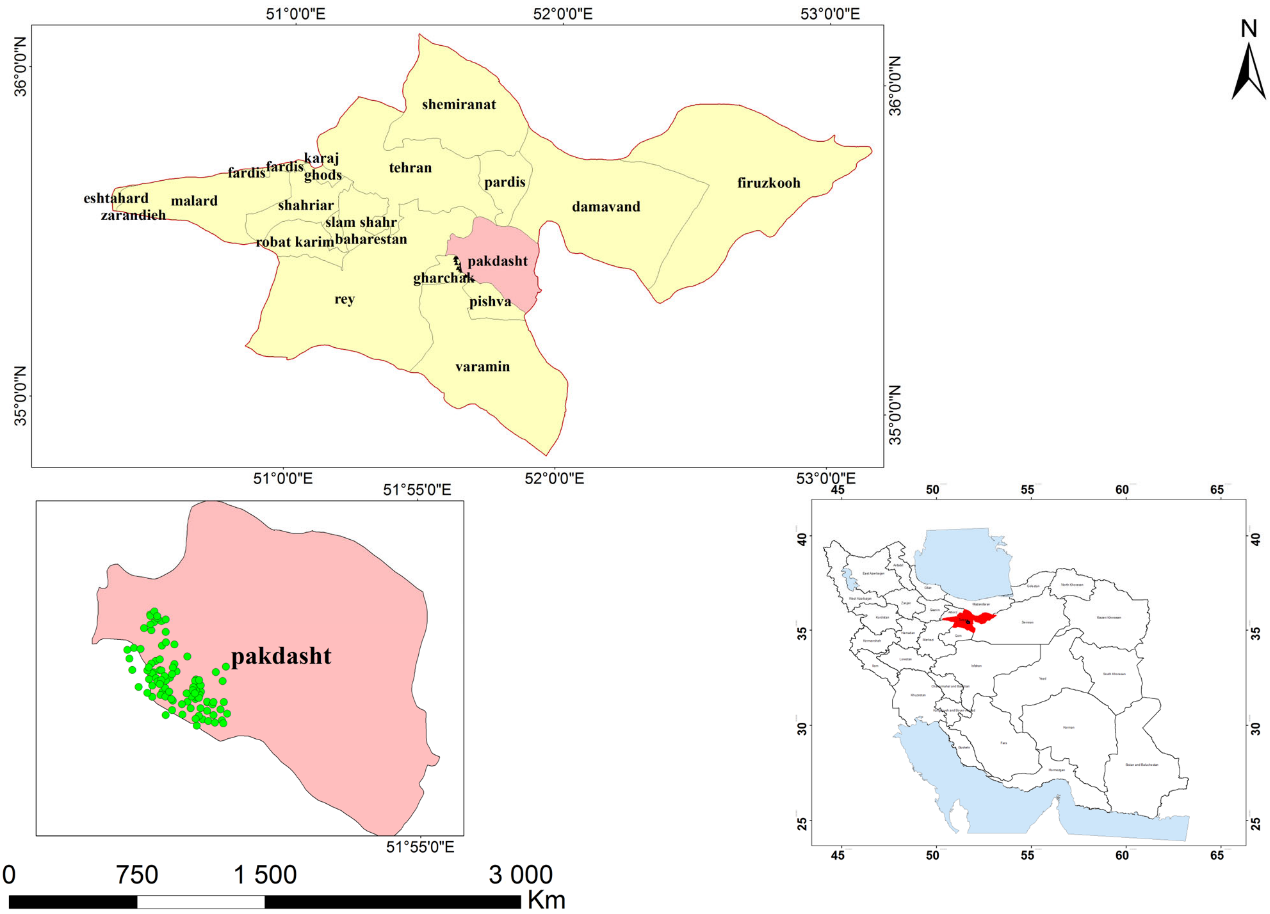

Figure 1. Iran country map and the location of Tehran province and Pakdasht. (The green dots show the exact location of the studied fields).

From plowing until harvesting, wheat fields of common varieties were tracked. In 104 wheat fields management practices were documented over the growing season period to predict prospective production and yield gap. The farms under study were each managed by one farmer. From soil preparation until harvest, each management procedure was identified in the surveyed fields. The time and frequency of tillage for cultivation, seeding date, and plant densities were all detected in the surveyed fields. The amount of nitrogen, phosphorus, and potassium fertilizers used was obtained from the information on their purchase by farmers. In addition, the dates of fertilizer use and the amount used each time were periodically asked from the farmers. The number of times the lands were irrigated during the water rights period of each region when farmers had time to use river or well water, as well as the date of each irrigation, was recorded. The lands in this region were irrigated using flooding. Farmers in coordination with agricultural experts determined weed, disease, and pest control. As a result, the precise amount consumed of herbicide and pesticide and when spraying occurred during the growing season was determined. Dates of product harvest were recorded by agricultural experts. Field management methods were surveyed beginning on September 18th of each study year. Also, soil parameters such as Total Neutralizing Value, soil phosphorus, soil pH, organic carbon in soil, and soil salinity were examined for all fields. Sampling was done from a depth of 0 to 30 cm from the soil surface. Electrometric analysis was used to determine the pH of mixed soil samples in a suspension of 1:2.5 dirt to water [37]. The wet digesting methodology of Walkley and Black [38] was used to measure the organic carbon content, and the semi-micro Kjeldahl technique [39] was used to measure the total nitrogen. The Olsen's approach [39] was used to calculate the phosphorus concentration. This was done by sampling before planting. The electrical conductivity (EC) of soil solution, which is measured in dSm^{-1}, was used to quantify soil salinity as the concentration level of the dissolved salts [40].

A portable leaf area meter was used to gauge the size of wheat plant flag leaves, the second and third leaf from the top of the plant (Model Li-3000C, LICOR Biosciences, Lincoln, NE, USA). In 2019 and 2020, ten wheat plants from each treatment were sampled in the middle of the filling stage. The same portions of flag leaves from wheat plants were chosen and measured in 2019 and 2020 at the middle of the filling stages using a hand-held chlorophyll meter (SPAD-502, made by the Konica Minolta Company, Tokyo, Japan; measurement area: 2 mm $\times$ * 3 mm). For measurement, ten flag leaves from each treatment were taken and were measured three times. The harvest index was obtained by dividing the grain yield by the total amount of biomass above ground level in the physiological maturity stage.

All the wheat fields studied were chosen with the assistance of local agricultural ministry specialists and primary data such as field areas were extracted from the local ministry office. Farmers were not allowed to interfere with the recording and monitoring of the farming methods in the fields (chosen variables). The 104 wheat fields that were tracked represented all the region's major production methods. Following that, all management information from the surveyed fields was gathered. First, all research variables were segregated in the questionnaire for data collection. Throughout the growing season, from plowing to harvest, chosen wheat fields were monitored in terms of acreage, management approaches, input use, and yield. For greater accuracy of the acquired data, the actual yield of each analyzed wheat field was recorded independently after the growing seasons. Considering that the investigations were carried out in the growing season of fall planting (in the period mentioned above), one harvest and measurement of the grain yield was done at the end of the growing season.

The Yield Gap was investigated using the CPA method. The stepwise regression model [41–43] was chosen to discover factors that characterized variance in wheat yields using the CPA approach [21,22,44]. The link between all evaluated factors and wheat yield was analyzed using a regression model to determine the optimum yield models. The average wheat yield was calculated by taking the average of the assessed model's observable variables (Xs) in the wheat fields. After that, by entering the ideal level of variables in the CPA model, the highest amount of expected yield was computed. In the same context, the yield gap was calculated as the difference between potential and actual yield. The contrast between the observed data of each variable and its coefficient was then used to compute the proportion of the yield gap for every variable. The overall yield gap was calculated by adding the yield gaps of each variable. SAS software, version 9.4, and SPSS version 26 were used to analyze the CPA model. Figures and maps were drawn with the help of R, Excel, and SPSS version 26 software.

3. Results

3.1. Production Process Documentation

An analysis of the data from 104 wheat fields showed that the production history of the farmers ranged from 1 to 68 years (Table 1). In under-investigation wheat fields, 175 to 375 kg ha^{-1} of seeds were used. The study of the seeding data revealed that farmers began planting between 29 September and 8 December (Table 1).

Table 1. Descriptive statistics of the studied variables in 104 wheat fields.

Variables	Unit	Mean	Minimum	Maximum	SE	CV (%)
Farming experience	Year	26.34	1	68	1.58	59.60
Farmer age	Year	45	18	83	1.45	32.04
Seed rate	kg ha^{-1}	253.57	175	375	4.17	16.29
Sowing date	Day of year	294	49	342	4.66	15.71
Total Neutralizing Value	%	18.12	11.24	43.89	0.60	33.16
Soil phosphorus	ppm	10.10	1.80	57.18	1.41	138.41
Soil pH	pH	8.18	6.03	8	0.08	10.63
Organic carbon in soil	%	0.61	0.14	1.23	0.03	54.09
Nitrogen fertilizer	Number	1.59	0	3	0.10	62.89
Total nitrogen	kg ha^{-1}	206.73	0	500	13.61	65.18
Potassium	kg ha^{-1}	10.45	0	100	3.01	285.16
Number of irrigations	Number	5.47	3	8	0.12	21.57
Insecticide	Frequency	0.85	0	2	0.06	67.05
Insecticide volume	Liter ha^{-1}	0.55	0	2	0.05	98.18
Herbicide	Frequency	0.85	0	2	0.07	84.70
Herbicide volume	Liter ha^{-1}	0.75	0	2	0.06	81.33
Length of growing period	Day	226	120	260	2.58	11.32
Harvesting duration	Start of spring	86.07	61	109	0.79	9.09
Wheat yield	kg ha^{-1}	5377	2600	7600	0.12	0.02

In this sense, there was adequate time to prepare seedbeds. From the second week of September until the third week of November, the initial plowing of fields was done to prepare the seedbed in the fields. The information in Table 1 showed that the total nitrogen (N) rate ranged from 0 to 500 kg ha^{-1}. Not all 104 fields were fertilized with phosphorus, so the utilization range was from 0 to 300 kg ha^{-1} (Table 2). According to data analysis, potassium usage ranged from 0 to 100 kg ha^{-1} (Table 1). In terms of nitrogen intake during the tillering stage, the 104 wheat fields under study ranged from 0 to 325 kg ha^{-1} (Table 2). In the studied wheat fields, nitrogen application data were ranging from 0 to 3 times (Table 1). During the growing season, most farmers consider the importance of fertilization, irrigation, and controlling pests, weeds, and illnesses [21]. The findings suggested that further work was needed to promote the adoption of nitrogen fertilizer splitting and the use of soil analysis by wheat farmers.

Table 2. The wheat yield gap numerical value and the fraction of each independent variable to contributing to the CPA output equation.

Variables	Unit	Coefficients	CPA Model Variables				Predicted Yield		Yield Gap (Kg ha^{-1})	Yield Gap (%)
			Min	Mean	Max	Best	Mean	Best		
Leaf Chlorophyll Content (X_1)	μgcm^{-2}	75	25	39.47	54	54	2960	4050	1089	29
Irrigation Stem Extension (X_2)	DOY	−4	1	83.64	329	1	−334	−4	334	9
LAI (X_3)		153	1.27	4.4	6.29	6.29	673	962	289	7.7
Soil Salinity (X_4)	dSm^{-1}	−275	0.55	1.68	3.45	0.55	−462	−151	313	8.2
Field Area (X_5)	ha	27	1	8.34	31	31	225	837	612	16.3
Phosphorus (X_6)	kg	−3	0	74.84	300	0	−224	0	225	6
Nitrogen at Tillering stage (X_7)	kg	3	0	126.88	325	325	380	975	594	16
Harvest index (X_8)		3151	0.31	0.42	0.51	0.51	1323	1607	292	7.8
Wheat yield (kg ha^{-1})	kg ha^{-1}	–	2600	5377	7600	–	5568	9316	3748	100

In the fields under study, pesticide use occurred somewhere between 0 and 2 times per crop year. The number of steps in the herbicide use ranged from 0 to 2. According to data analysis, product harvesting took place 61 to 109 days following 21 March (start of spring). The results showed that in 104 wheat fields, the range of wheat yield was 2600 to 7600 kg ha^{-1} (with an average of 5377 kg ha^{-1}) (Table 2).

3.2. Estimating Yield Gap Using the CPA Method

Table 2 displays the findings of the stepwise regression model that show the variables that significantly affect the yield; the regression model has been separated from the other calculated variables. The CPA model evaluated grain yield per unit area as a dependent variable. Farming experience, seed rate, sowing date, the amount of leaf chlorophyll, irrigation turn date, leaf area index (LAI), soil salinity, field area for each farmer, amount of phosphorus intake, amount of nitrogen used at the time of planting, and harvest index, on the other hand, were independent variables (Table 2). The ultimate regression models with eight independent variables were selected from the eighty-two examined variables. The ultimate stepwise regression yield equation is as below:

$$Y\ (\text{kg ha}^{-1}) = 1036 + 75\,X_1 - 4X_2 + 153X_3 - 275X_4 + 27X_5 - 3X_6 + 3X_7 + 3151X_8$$

In the equation, Y is the wheat yield (kg ha^{-1}), X_1 is the amount of leaf chlorophyll, X_2 is Irrigation at the stem extension stage (day of the year), X_3 is the leaf area index (LAI), X_4 is soil salinity, X_5 is field area, X_6 is phosphorus consumption, X_7 is nitrogen used at the tillering stage, X_8 is the harvest index; these are for the evaluation of each of the factors that influenced the wheat yield. According to the results of the above equation mentioned in Table 2, if the leaf chlorophyll content was 54 μgcm^{-2}, the wheat production was maximum, leading to the production of 4050 kg ha^{-1}. The yield gap created by this variable was 1089 kg ha^{-1}. The irrigation at the stem extension stage on DOY one had the least negative effect on the yield and this variable showed the value of 334 kg ha^{-1} of yield gap. The LAI variable with an optimal value of 6.29 justified the yield of 962 kg ha^{-1} of the total yield. In the study conducted, LAI showed a yield gap of 289 kg ha^{-1}. The soil salinity of the farms at the lowest level, 0.55 dSm^{-1}, reduced the yield by 151 kg ha^{-1}, while the resulting yield gap was 313 kg ha^{-1}. The largest area of the farms under study with 31 hectares, determined 612 kg ha^{-1} of potential yield. The yield gap of the smallest farm in terms of the area was 612 kg ha^{-1}. The results of the regression model obtained from CPA indicated that if phosphorus fertilizer was not used, the amount of yield change on this variable was zero, but if it was used to the maximum, the yield gap resulting from it was 225 kg ha^{-1}. Using 325 kg ha^{-1} of nitrogen fertilizer in the tillering stage, which is the optimal amount in the equation, could show 975 kg ha^{-1} of yield. Failure to use this variable caused a 594 kg ha^{-1} of yield gap. The harvest index of 0.51, justified the yield of 1607 kg ha^{-1}, and for this variable, 292 kg ha^{-1} of yield gap was determined.

3.3. The Range of CPA Approach Variables and Their Correlation

The CPA approach showed that the amount of chlorophyll, LAI, and harvest index (Figure 2a–c) had more contribution to the wheat yield gap than other plant traits. The LAI and the amount of chlorophyll showed the same pattern. Figure 2d shows that the northern and western parts of the studied area had elevated levels of soil salinity. Findings in Figure 3 show crop management and yield distribution in the studied areas. Cultivation areas in many of the studied fields were small, which negatively influences the yield gap (Figure 3a).

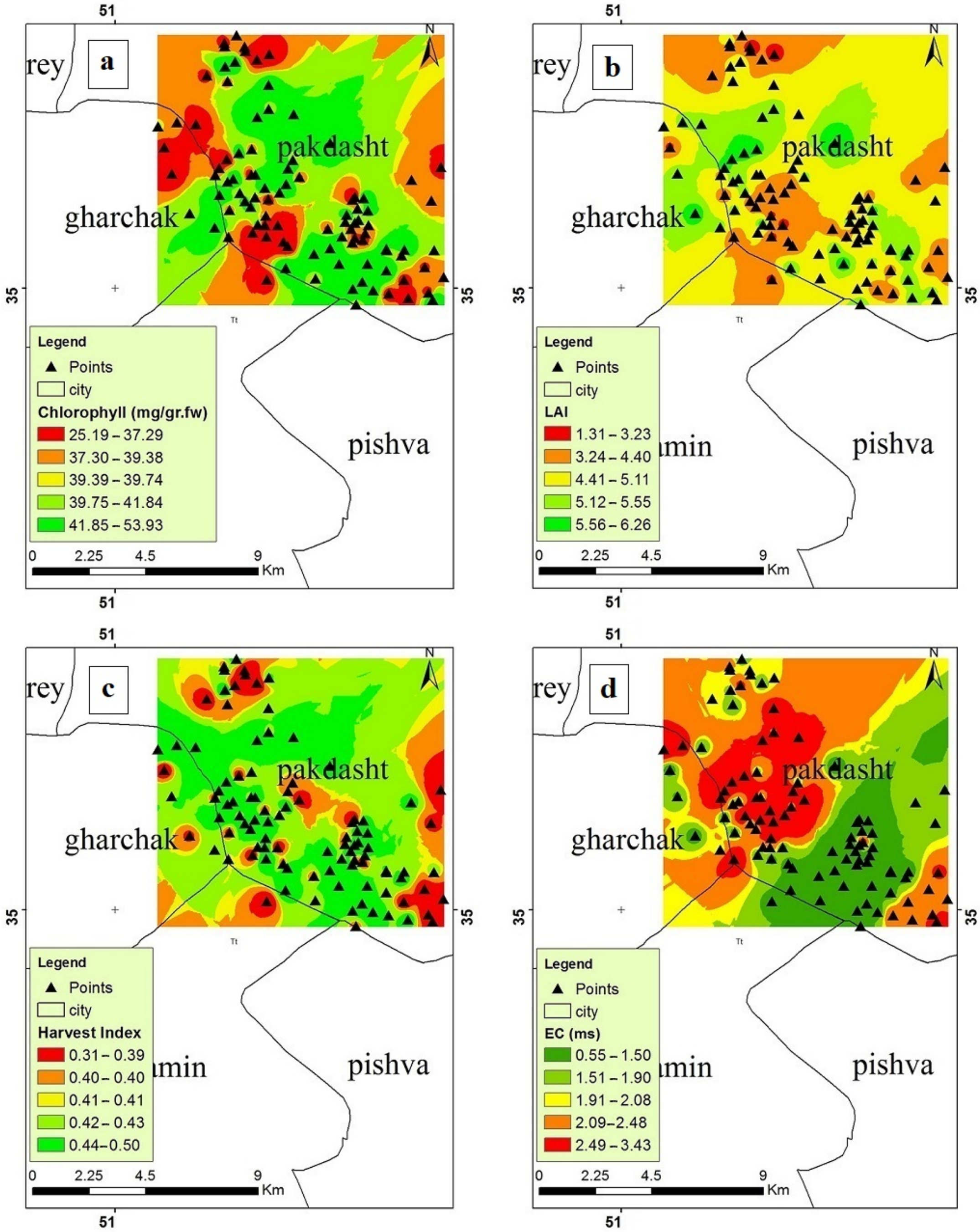

Figure 2. The range of plant and soil variables with a high impact on the wheat yield gap in the fields studied in Varamin Plain of Pakdasht, extracted from the results of the CPA approach. (**a**) The amount of leaf chlorophyll; (**b**) LAI; (**c**) Harvest Index; (**d**) Soil salinity.

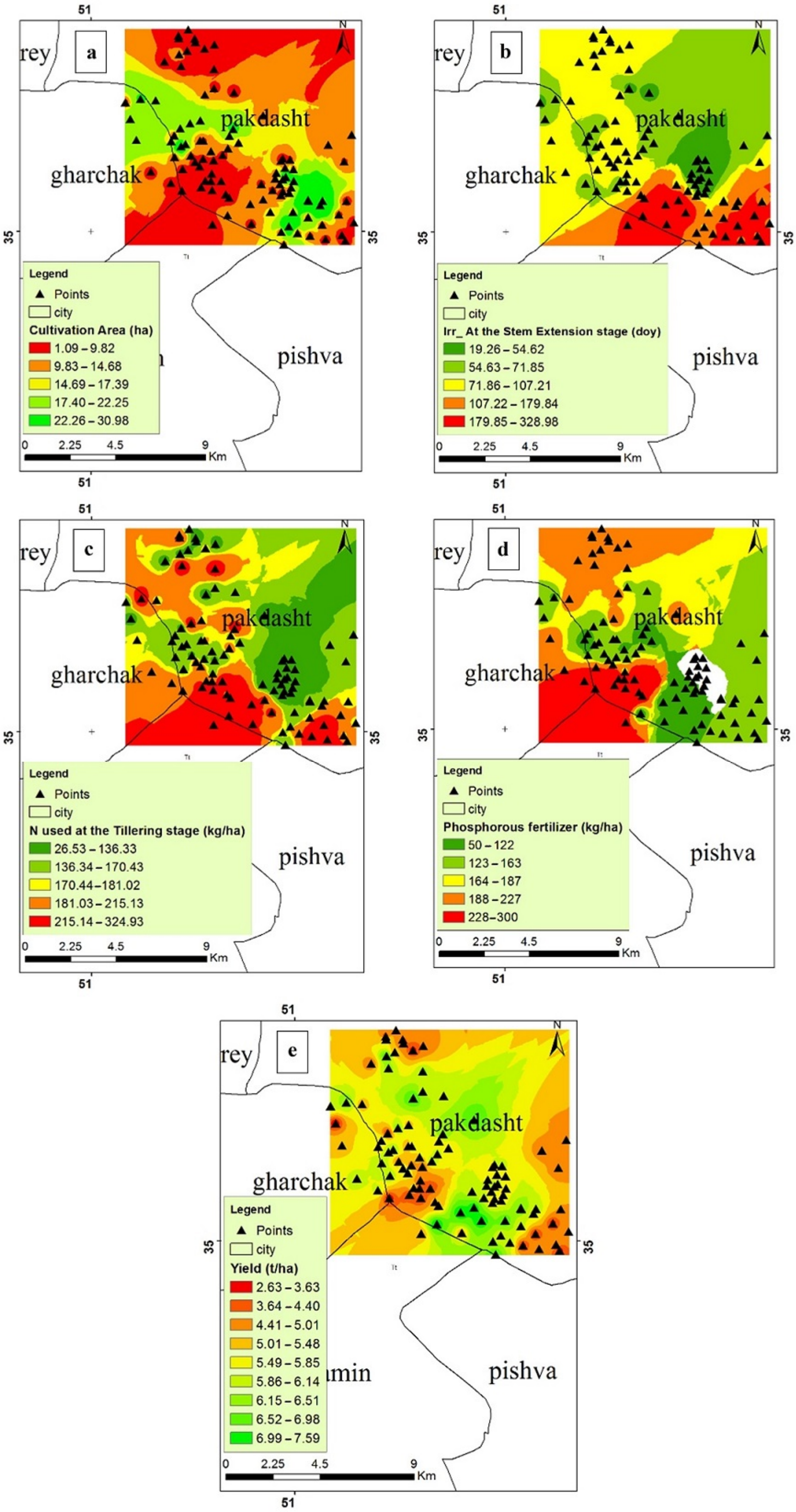

Figure 3. The range of crop management variables with a high impact on the wheat yield gap (**a**–**d**) and the range of wheat yield in the fields studied in Varamin Plain of Pakdasht, extracted from the results of the CPA approach. (**a**) field cultivation area; (**b**) the irrigation date at the stem extension stage; (**c**) nitrogen used at the tillering stage; (**d**) phosphorus consumption; (**e**) wheat yield.

The dates of irrigation in the stem extension stage in the studied southern areas were delayed (Figure 3b). In Figure 3c–d, red areas are those where farmers use fertilizers in opposite directions from the CPA results. Using less nitrogen fertilizer and more phosphorus fertilizer in the same regions caused the yield gap in these areas. The distribution of wheat yields in the study areas shows that the central areas had better yields (Figure 3e).

The correlation between the performance and the variables of the CPA regression model in the two years of the study is shown in Figure 4, as well as the correlation between each of the variables. The wheat yield had the most significant positive correlation with the amount of flag leaf chlorophyll and harvest index; it had the most significant negative correlation with phosphorous consumption and soil salinity.

Figure 4. Correlation between eight variables extracted from the CPA approach in total and separately in two years of study. (From left to right, year 1 and 2, the amount of leaf chlorophyll, irrigation at stem extension stage, LAI, soil salinity, field area, phosphorus consumption, nitrogen at the tillering stage, harvest index, wheat yield). Significance level: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

3.4. Wheat Yield Limiting Factors and Yield Gap Prediction

Table 2 shows each variable that was used in the CPA model along with its statistical coefficient and actual value. The amount of leaf chlorophyll, the leaf area index (LAI), the field area for each farmer, the amount of nitrogen utilized at the tillering stage, the harvest index, and their maximum levels were chosen to determine the proper conditions for the variables. Negative variables included the irrigation at the stem extension stage, the amount of phosphorus used, and the salinity of the soil. Because of the observed detrimental effects of these factors, a small amount of them was determined to be the optimal amount. The least amount of these variables was therefore the optimal value (Table 2).

The increase in wheat output resulting from the difference between the best and mean values of leaf chlorophyll and leaf area index were equal to 29 and 7.7 percent, respectively, of the overall increase in wheat yield of 1089 and 289 kg ha^{-1}. The irrigation at the stem extension stage's yield difference was 334 kg ha^{-1}, or 9 percent (Table 2). The impacts of the two factors of field size for each farmer and the quantity of nitrogen utilized at plantings were significant, and management of these factors can minimize the yield gaps in each farmer's field.

The distribution of variables on the wheat yield was shown in Figure 5, along with the farmer's actual yield and anticipated potential yield, showing that all this difference in yields may be decreased with proper management of the variables used in the CPA model. The relationship between the observed and expected yields, as shown in Figure 6, revealed that the CPA model precision (R^2 = 0.67 **) is appropriate and may be used to calculate potential yield, estimate the yield gap, and determine the proportion of descriptive variables. The results showed that the CPA model's maximum and average yields were 9316 and 5568 kg ha^{-1}, respectively. In contrast, the highest and mean yields in the farmer's fields were 7600 and 5377 kg ha^{-1}, respectively, with a total forecasted yield difference of 3748 kg ha^{-1} (Figure 7).

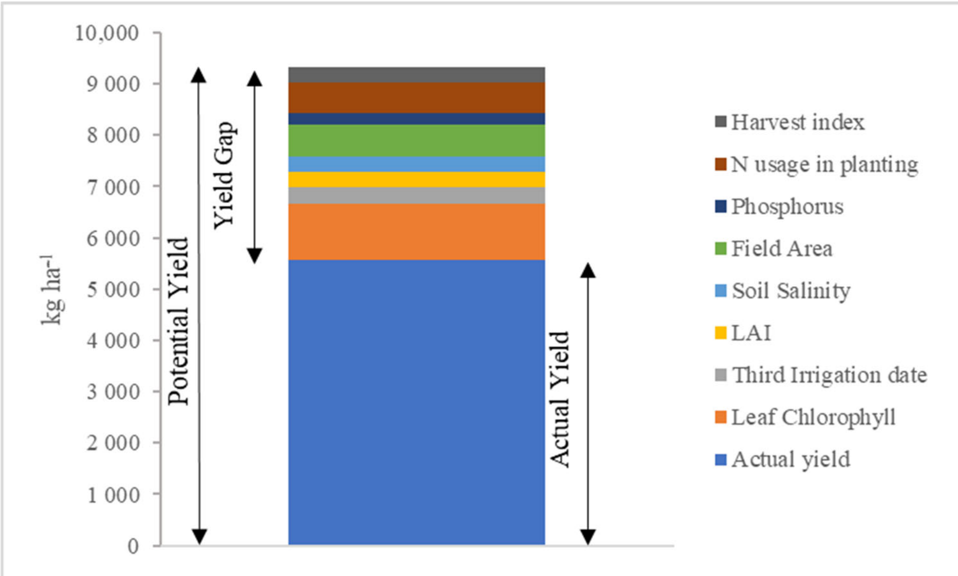

Figure 5. The extent of the major yield gap limiting factors.

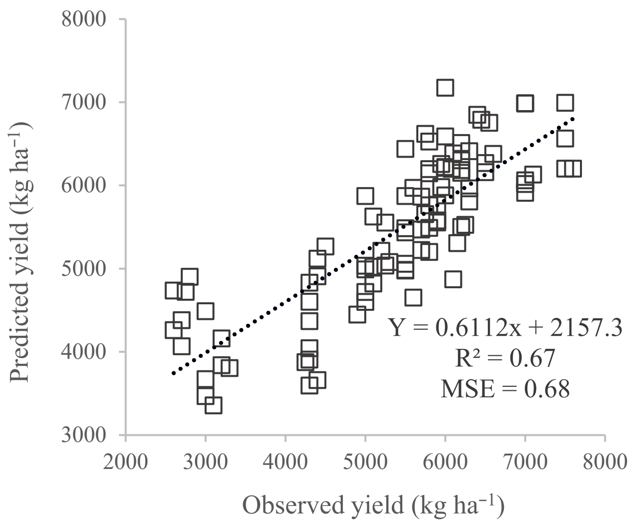

Figure 6. The relevance among predicted and observed yield values.

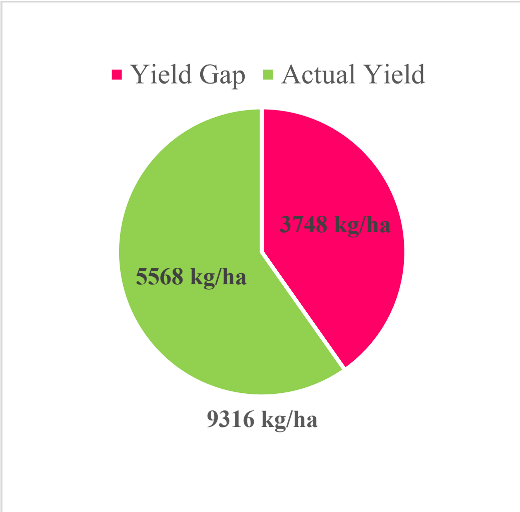

Figure 7. Potential yield, actual yield, and yield gap for the investigated area of Varamin plain in brief.

4. Discussion

Crop management strategies can be improved to lessen the number of necessary inputs and ease environmental demand on natural resources [45,46]. Good agricultural practices resulted in greater crop performance, which required fewer NPK fertilizers and low energy input, according to a different study conducted in the same area [47]. So, as a thorough way to identify the yield gap and its reasons at a specific place, CPA has been utilized to study limiting factors. A thorough yield gap analysis must reveal prospective yield, actual yield, and yield gap, as well as the reasons for the gap and their significance [20]. By CPA, it is possible to quantify the yield gap, its primary causes, and their importance. This method can only be applied to a set of management methods that can be evaluated using a large sample of diverse farms. Despite their shortcomings, these techniques can be easily applied in developing nations where there is a large yield gap and the largest agronomic potential to improve food security worldwide.

According to the CPA results, the bigger yield gap and fraction of influencing factors show that a sizable component of this yield gap could be remedied with proper crop management. Crop yields rarely reach their potential and only a portion of what was possible, is harvested as a true crop. However, the research's objective was to determine the wheat yield gap specifically in the Varamin plain, which is in the Province of Tehran's southwest.

Due to the widespread use of information obtained from leaf chlorophyll content in remote sensing methods, it was used among the entered variables to determine the CPA model. This variable with a share of 4050 kg of potential performance and showing 1089 kg of performance gap plays a significant role in the model, which can be used for future research with remote sensing methods [48,49]. According to the regression equation, flood irrigation during the stem extension stage had a negative effect on the yield and showed a yield gap of 334 kg. Since in this growth stage of wheat, it is often raining in the study site, this decrease in yield can be attributed to the increase in wheat stem length due to the absorption of more water and the subsequent wheat lodging in these fields. In agreement with Shurong Hao et al., direct dry irrigation could significantly reduce plant height and internode length compared to conventional flood irrigation; however, lodging resistance notably improved with irrigation at stem extension [50]. Soil salinity had a negative effect on all studied farms, which was shown in the regression equation in the form of yield reduction. Irrigation depletion and salinity significantly reduced soil available macronutrients (i.e., N, P, and K), especially in hypersaline soils due to higher salinity and less irrigation than evapotranspiration. As a result, high-saline soils, which often occur in combination with drought, hurt microbial activity, organic matter degradation, and reduced soil N, P, and K availability [51]. Given the importance of nitrogen and phosphorus fertilization in modern agriculture and the expansion of agricultural land, it is important to understand the effects of nitrogen and phosphorus fertilization on soil microbial community composition and potential function. The non-use of phosphorus fertilizer did not affect the yield potential and its amount was zero in the CPA model, and in case of use, up to 225 kg of yield gap was created. Since most of the soil texture of the study site was clay which can help phosphorous absorption [52] and the soil phosphorus level was acceptable in the soil test, it is possible that the use of phosphorus fertilizer had a negative effect on the soil microorganisms that facilitate the absorption of soil nutrients. Yun Liang Li et al. presented similar results to explain the use of phosphorus fertilizer. They said that soil nitrogen fertility management influenced nitrogen cycling processes by altering the related addition of archaea and bacteria to various phosphorus metabolic processes. Increased diversity caused by heightened nitrate assimilation is the predominant fungal reflex to nitrogen fertilization, whereas phosphorus fertilization adversely affects soil microbial community richness [53]. When phosphorus and nitrogen fertilizers were used and irrigation in the stem extension stage applied, it led to an increase in the chlorophyll content of the leaves, and this increase in the chlorophyll content, with its effect on photosynthesis and dry matter production, led to the expansion of the leaf surface. The expansion of the leaf surface influences the harvest index, increasing the grain yield and reducing the yield gap [54–56].

The causes of the yield gap's incidence need to be further investigated. The most probable outcomes that can result in improved performance and a smaller yield gap is changing the farm owner's management of the crop. Yield gap investigation also showed that there was a significant gap in the region's wheat production, indicating which management methods need to be changed and which ones were not required, considering the circumstances of grain production at the time. Improved management strategies were required to close the yield gap [15].

The predicted yield gap for wheat in this research by CPA is equivalent to the 40 percent reported by Mueller et al. [57] for wheat in Iran. They used agricultural simulation models to assess the global yield gap for the main cereals, including maize, wheat, and rice. Our results were also comparable to the 43% average yield gap estimate that was found using crop models on irrigated wheat in Golestan province in northern Iran [20]. Since crop models' yield gaps assume no restrictions from pests, diseases, or nutrient deficits, it was expected that crop models will produce a larger estimate of potential output. As a result, crop model yield gaps were larger.

Overall, the research findings showed that applying the CPA model to forecast yield gaps can help farmers to better understand how each variable will react. These comments can be used to specify the best management procedures and strategies for maximizing yield. On the other hand, applying the CPA model has a drawback because it only considers the impact of each variable on performance, rather than considering how varied factors interact to produce a given performance, and thus makes less relevant the effect of the interaction of variables on performance [25].

It is incredibly significant to note that additional models to predict potential yield, such as using plant models with CPA, might highlight key production-related bottlenecks in a region. Choosing an alternative managerial strategy and getting the best performance is crucial to consider the potential yield as well as the severity and impact of yield-restricting issues. Depending on the type of agricultural plants, different management aspects are more crucial in each study region. According to this perspective, Oerke [58] used meta-analysis to evaluate yield loss caused by the impact of several biotic stressors, such as diseases, viruses, insects, and other organisms. He stated that the average yield loss for grains for two years was 25%. According to Savary et al. (2012), rice yield reduction in Asia's tropical region was 34%. In a global simulation analysis for the main grains grown worldwide, including maize, wheat, and rice, there was an attainable yield disparity of around 75 percent [57]. Other researchers have claimed that although it is useful to determine the yields that can be achieved in a specific region using the ideal genotypes, environmental conditions, and management, it is not possible to guarantee that there will be no biotic and abiotic stress during the plant growth period. As a result, these functions were not sufficient estimates of regional potential concerning climatic and soil conditions. Maximum yields in these experiments can potentially be decreased by certain regional meteorological conditions. For instance, each area's seasonal radiation affects whether an achievable yield is possible.

Despite all the justifications, it can be stated that the anticipated yield gap closely resembles the usesful concept of an achievable yield gap as it shows the differences between the actual farm produce and prospective yield in connection to regional environmental circumstances. Implementing years' frequency is one of this study's limitations. The estimation of the effect of climate and weather changes is more precise when the study spans a larger number of years. The effort to measure the yield gap necessitates the use of suitable techniques [21]. Finding the most crucial management methods is crucial for reducing the yield loss of the researched region [15]. Additionally, this understanding is essential to identify research priorities and to educate policymakers on how to attain food security without harming the environment [18]. The fact that effective crop plant management may be environmentally more beneficial than inefficient crop management is another crucial justification for closing yield disparities through field operations [59].

5. Conclusions

Using a large sample of farms representing a variety of farming approaches, the CPA method was able to quantify some production gaps, their primary causes, and the relative weight of each cause. Even if it is conceivable, local farmers may not find it cost-effective to achieve yields beyond 80% of their potential output because of the cost of machinery, fertilizers, and pesticides as well as the overlap with planting seasons. Based on the results, a considerable portion of the potential yield gap may be compensated with suitable practices, as evidenced by the bigger yield gap and the share of each element affecting the yield gap. The results showed that the CPA model had a potential yield of 9316 kg ha^{-1} and the predicted yield gap was 3748 kg ha^{-1}. In this model, the amount of leaf chlorophyll (29%), the irrigation date at the stem extension stage (9%), leaf area index (7.7%), soil salinity (8.2%), field area (16.3%), phosphorus consumption (6%), nitrogen used at the tillering stage (16%) and harvest index (7.8%) had more role in achieved yield. It was determined that the CPA approach, as used in the study, was inexpensive and straightforward; it can identify the yield gap and its causes in a district without the need for costly experiments. As a result, it is demonstrated that model precision is suitable for yield gap assessment and can be employed in developing nations, where the biggest yield gaps exist.

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