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# YIELD GAP ESTIMATION OF RAPESEED (*Brassica napus* L.) IN NORTHERN IRAN

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## ABSTRACT

**Understanding yield-limiting traits can help researchers reduce yield gap, a key step in increasing yield and sustainability. This aim of research was monitoring 100 fields of farmers to identify the most important variables to enter into a CPA model (comparative performance analysis) for the yield gap in northern Iran in 2016 to 2017. Of the 150 variables studied in the first experiment, eight independent variables were chosen for the final model. In the yield model, the average and maximum yields were 2536 and 4265 kg ha$^{-1}$, respectively, with an estimated yield gap of 1729 kg ha$^{-1}$. This yield gap was related to seed usage, planting date, fallow and rice cover-crop equal's 124, 101, 242 and 245 kg ha$^{-1}$ includes 7.17, 5.84, 14 and 14.17% of total yield increase. The yield increasing related to the effect of crop rotation, potassium usage, nitrogen after flowering and top-dressing frequency was 212, 295, 314 and 196 kg ha$^{-1}$ equals 12.26, 17.06, 18.16 and 11.34%. Accordingly, the model's precision is good and can be applied both to estimate the quantity of yield gap and to determine the portion of each constraint in the yield variables. Importantly, as the calculated yield potential is reached based on actual data in each paddy field, the yield potential is attainable.**

**Keywords:** canola, documentation, potential yield, field management, yield gap.

## INTRODUCTION

Sustainable food security is the ultimate goal of agricultural production systems. The global human population is predicted to grow substantially through 2050, necessitating enormous increases in food production as well as reductions in food waste (Fedoroff, 2015). The final capacity of food production in the world is limited by the amount of suitable land and available water resources for crop production as well as the biophysical limits of crop growth (van Ittersum et al., 2013). Reducing the gap between the yields that are current achieved by farmers and those potentially attainable using the cultivars most compatible with the environment, available water resources, as well as soil and crop management practices is the key to overcoming the nutritional challenges we face in the coming decades (Hochman et al., 2016; Hosseinzadeh et al., 2016). Here, yield gap analyses provide a quantitative estimate of the potential for increasing production capacity, which is an important component in the design of food security strategies at the regional, national and global levels (van Wart et al., 2013). Two variables - seedling age and transplanting date-have been entered into the comparative performance analysis (CPA) equation. This prompted examining the seedling age of local and improved rice cultivars in field experiments to select the best seedling age for each group of cultivars. Worldwide, however, this analysis has more closely involved soil factors (nutrient content, organic matter, acidity, etc.) and yield estimations (Shatar and Mcbratney, 2004; Kitchen et al., 2003; Tittonell et al., 2008). Separate studies have examined the relationships between yield and rainfall, evapo-transpiration, nitrogen consumption, pests, diseases and plant density (Patrignani et al., 2014; Grassini et al., 2013; Tasistro, 2012; Huang et al., 2008; Tittonell and Giller, 2013). Nonetheless, estimating potential yields and determining the minimum inputs to achieve potential yields

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has received less attention. Simulation models can be used for this purpose (Abeledo et al., 2008; Aggarwal and Kalra, 1994; Menendez and Satorre, 2007). Understanding the full potential as well as the extent and the effect of each limiting factor on yield separately plays an important role in determining alternatives management strategies to achieve maximum yield. Studies for rice plants can be used to analyze the rice yield gap in organic and conventional cultivation systems elsewhere, for example in the Mediterranean (Delmotte et al., 2011). They can also be use to determine the factors influencing the yield variation of flooding rice in southern-central Benin (Tanaka et al., 2015); determine the factors behind the rice yield stagnation in floodplain systems in the Senegal River Valley (Tanaka et al., 2015); analyze the yield gap of rice planting systems in the United States (Espe et al., 2016); simulate the global rice yield gap (Mueller et al., 2012); determine the yield gap of rice in China (Xu et al., 2016); conduct yield gap analyses of rice in the Philippines using modeling (Silva et al., 2017); and estimate the yield gap of rice in Netherlands to be 1855 kg $ha^{-1}$ (Kayiranga, 2006).

Multiple studies have shown that the first step in reducing the yield gap is to identify the key variables that restrict yield. This calls for understanding yield-limiting traits. Reducing the gap not only increases yield and production, but also improves land use and human resource efficiency, which in turn reduces production costs and increases yield sustainability. This aim of the research was monitoring of 100 fields of canola to quantify the rice yield gaps and identify the most important variables entered in CPA models in Mazandaran province, northern Iran.

## MATERIAL AND METHODS

### Monitoring of 100 farmers' paddy fields

### Description of the region

This experiment was carried out in east of the Mazandaran province, in 2015-2016 and 2016-2017. Mazandaran province city is located in the northern part of the Alborz Mountains range and south of the Caspian Sea in northern Iran. The experimental region was geographically situated at 36°39' N latitude and 53°19' E longitude, west of the Mediterranean Sea.

The mean annual rainfall in the coastal area of the province is 977 mm. The maximum rainfall occurs in fall, the minimum in spring. Hot and humid summers and mild and humid winters are the main characteristics of the weather here. Therefore, the weather in some parts of this area is similar to that of the Mediterranean. Solar radiation (MJ $m^{-2}$ $d^{-1}$) was estimated using sunshine hours and extraterrestrial radiation (Soltani and Hoogenboom, 2003a; 2003b; Soltani and Sinclair, 2012). To calculate the solar radiation, the *Srad_calc* program was used. This program uses the sunshine hour data to calculate solar radiation. The *PP_calc* program was applied to evaluate day length. The *Srad_calc* and *PP_calc* programs can be downloaded from https://sites.google.com/site/CropModeling.

### Data collection

All the agricultural practices in this research, from the primary plough and seedbed preparation to harvest, was recorded by paddy field monitoring. For estimating yield gap, all agricultural practices were recorded, from seedbed preparation to the harvesting stage, in 100 fields via field monitoring. The method of each agricultural practice in the studied fields was determined for each of the phases of preparing soil, planting, cultivating, and harvesting.

Some important management measures were frequency and time of tillage operations (e.g. plough and disk cultivation), sowing date, seeding date, seeding rate, frequency and the amount of nitrogen fertilizer, the amount of phosphorus ($P_2O_5$) and potassium ($K_2O$) fertilizers, irrigation frequency and regimes, time and frequency of weed, disease and pest controls and harvesting date. Time of operations (e.g. planting date) was considered as day since 23 September, the beginning of autumn. The list of management variables recorded in the studied rapeseed fields are presented in Table 2. For several management practices/input, it was not possible to fit a boundary line because there was no relationship between the variables and the maximum yields. Therefore, crop yield was not limited by these variables, at the level where they are currently practiced.

The studied fields were selected with the help of local experts to represent a wide range of situations. All the management practices/inputs (variables) were monitored and recorded without interfere with farmer operations. The manner of identifying farms covers all main production methods. Then, information pertaining to farm management was collected. For data collecting, all agricultural variables were first separated. In total, studied fields were different with respect to field area, agricultural practices, inputs used and seed yield were evaluated over the growing seasons from seedbed preparation to harvest. At the end of the growing season, the actual yield was registered.

### Estimation of yield gap by CPA method

In order to determine the yield model (production model), the relationships between all the variables were measured and the yield was evaluated using the regression method (Soltani et al., 2016). The final model was obtained through the controlled trial and error method, which can quantify the effect of yield limitations.

The average paddy yield was calculated by the model by placing the observed average variables (Xs) in the fields under study in the yield model. Thereafter, we calculated the maximum obtainable yield by putting the best observed value of the variables in the yield model. The difference between these two approaches is considered the yield gap. The difference between multiplying the average observed value for each variable by its coefficient, and multiplying the best observed value for the same variable by the coefficient of the same variable, presents the value of the yield gap for that variable. The ratio of yield gap for each variable to the total yield gap represents its share in creating the yield gap (in percent). Different procedures of the software SAS version 9.1 were used for this analysis.

## RESULTS AND DISCUSSION

### Yield gap estimation by CPA method

### Production model

The results of the stepwise regression to determine the most important management variables that affected the yield and production model are presented in Table 1. In this regression model, the seed yield per unit area was considered as a dependent variable. The other variables such as seed usage, crop rotation, planting date, fallow, potassium usage, nitrogen usage after flowering, fertilizer top-dressing frequency and cove crop of rice harvesting were considered as independent variables, and the result was presented in the final equation. Finally, using this production equation, the actual farm yield, the attainable yield, and the share of each variable on yield reduction were determined. Therefore, from about 150 studied variables, the stepwise model (final regression equation) was selected with eight independent variables (Table 1). The final yield equation is as follows:

$$Y\ (\mathrm{kg\ ha^{-1}}) = 2120 - 8\ X_1 + 245\ X_2 - 14\ X_3 - 18\ X_4 + 4\ X_5 + 27\ X_6 + 292\ X_7 - 29\ X_8$$

where Y is the seed yield in kilogram per hectare, $X_1$ is seed usage, $X_2$ is crop rotation, $X_3$ is planting date, $X_4$ is fallow, $X_5$ is potassium usage, $X_6$ is nitrogen usage after flowering, $X_7$ is fertilizer top-dressing frequency and $X_8$ is cover crop of rice. These continue for the evaluation of each of the factors that influenced the paddy yield.

### Seed yield limiting factors and yield gap estimation

Table 1 presented the variables applied in the production equation with the mean, minimum and maximum values observed in the paddy fields. The characteristics of the variables applied in the model as the average, minimum, maximum, and best values that could be applied in the yield regression model are presented in Table 1. To achieve the best condition for the variables including crop rotation, potassium usage, nitrogen usage after flowering, fertilizer top-dressing frequency with positive effect, their maximum values were selected. Seed usage, planting date, fallow and cover crop of rice variables were negative variables and selected in small amounts, therefore, the optimal value was equivalent to the minimum of these two variables. The increase in seed yield caused by the difference between the best and the medium state of seed usage, planting date, fallow and cover crop of rice variables was equal to 7.17, 5.84, 14 and 14.17% of the total paddy yield increase of 124, 101, 242 and 245 kg ha$^{-1}$, respectively. The seed yield increase related to the effect of crop rotation, potassium usage, nitrogen consumption after flowering, fertilizer top-dressing frequency was 212, 295, 314 and 196 kg ha$^{-1}$, respectively, and equal to 12.26, 17.06, 18.16 and 14.17% of the total changes in yield (Table 1).

*Table 1.* Quantifying the canola yield gap and the contribution of each variable entered in the production equation in the CPA method

| Variable | Coefficients | Variable in model | | | | Predicted yield by model | | Yield gap (kg ha$^{-1}$) | Yield gap share |
|---|---|---|---|---|---|---|---|---|---|
| | | Min. | Mean | Max. | Best | Mean | Best | | |
| Intercept | 2120 | - | - | - | - | 2120 | 2120 | - | - |
| Seed usage ($X_1$) | -8 | 4 | 5.6 | 8 | 4 | -304 | -200 | 124 | 7.17 |
| Crop rotation ($X_2$) | 245 | 0 | 0.60 | 1 | 1 | 392 | 654 | 212 | 12.26 |
| Planting date ($X_3$) | -14 | 2 | 44 | 75 | 2 | -616 | -392 | 101 | 5.84 |
| Fallow ($X_4$) | -18 | 0 | 0.24 | 1 | 0 | -890 | -356 | 242 | 14.00 |
| Potassium usage ($X_5$) | 4 | 0 | 35 | 137 | 137 | 140 | 548 | 295 | 17.06 |
| N after flowering ($X_6$) | 27 | 0 | 10 | 25 | 25 | 270 | 675 | 314 | 18.16 |
| Top-dressing frequency ($X_7$) | 292 | 0 | 2 | 3 | 3 | 584 | 876 | 196 | 11.34 |
| Cover crop of rice ($X_8$) | -29 | 0 | 0.83 | 1 | 0 | -24 | 0 | 245 | 14.17 |
| Seed yield (kg ha$^{-1}$) | - | 1520 | 2425 | 3150 | - | 2536 | 4265 | 1729 | 100 |

Among the eight variables used in the model, the effects of potassium usage and nitrogen consumption after flowering were remarkable, which compensated for a significant part of the yield gap in the fields with the farmers managing potassium consumption and nitrogen splitting after flowering. The results listed in Table 1 show the total yield and the share of each factor limiting the production relative to it. In the production model, the average and the maximum yields were estimated to be 2536 and 4265 kg ha$^{-1}$, respectively, which is comparable to the average and maximum, yields (2425 and 3150 kg ha$^{-1}$).

The total yield gap estimated was equal to 1729 kg ha$^{-1}$. This means that there was a gap between the actual yields of the farmers and what they could have potentially harvested with 1729 kg ha$^{-1}$, which could be eliminated or reduced with better management (Table 1). The results in Figure 2 illustrate the contribution of each variable to the yield gap along with the actual and the potential yields.

Therefore, the actual yield and the potential yield were estimated to be 2536 and 4265 kg ha$^{-1}$, respectively, and the yield gap was 1729 kg ha$^{-1}$. This result suggests that this yield gap could be compensated. The findings in Figure 2 show the relationship between the actual yield (observed yield) and the predicted yield (simulated yield). These statistics shows that the accuracy of the model (production equation) is appropriate, and it can be used to estimate the yield gap and to determine the contribution of each production-limiting variable. With all these interpretations it can be said that the calculated yield gap in this study is close to that given by researchers regarding the attainable yield gap and shows the difference between the actual yield and attainable yield in relation to the environmental conditions of the area.

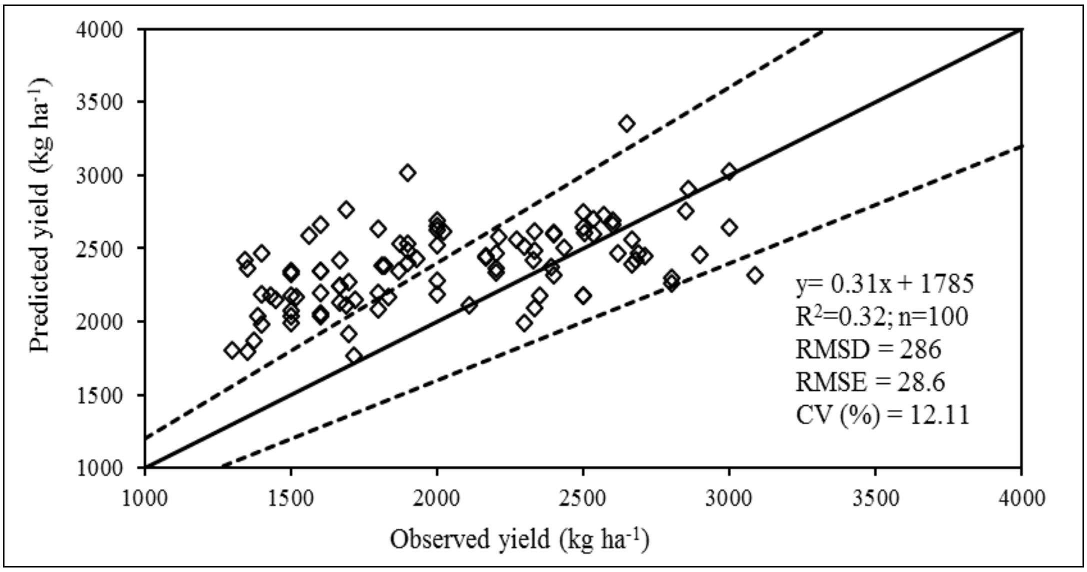

*Figure 1.* The relationship between observed and predicted yields.
Twenty percent of the differences between the two yields are shown by dashed lines

One of the limitations of this research is the number of years of the implementation; the more the years spent, the more accurate the estimation of the impact of climate and climate fluctuations. To reduce the yield gap, it is necessary to specify the yield limits in a particular area (van Ittersum et al., 2013). However, there is no such limitation on the potential yield obtained at a research station or in potential yield simulation with plant models. The goal of many researchers is to increase yield to a reasonable level for maintaining food prices to the extent that it is both desirable for the consumer and the product price can cover the costs for the farmer as well. Reducing the yield gap requires specifying the yield limits in a particular area (van Ittersum et al., 2013). However, there is no such limitation on the potential yield obtained at a research station or in a potential yield simulation with plant models. The ultimate goal of most researchers is to increase yield to a reasonable level to maintain food prices at a level that it is both desirable for consumers and covers the costs for farmers. Generally, our results demonstrate that using the CPA method in yield gap studies can illustrate the effects of managerial factors by identifying the contribution of each variable. Using these effects, the best management and planning responses to achieve the highest yield can be determined. This method also has certain disadvantages: it considers the interaction of variables affecting yield to be non-significant and only analyzes the impact of a variable on yield. In reality, yield is the result of the interaction of a set of factors (Kitchen et al., 2003). Importantly, the use of other methods for estimating potential yields, such as plant models combined with boundary line analysis, can reveal important points regarding production limitations in a region. Understanding potential as well as the extent and effect of yield limiting factors separately is important in determining alternative management strategies to achieve maximum yield. The importance of each factor in each region changes with crop type. In this context, Oerke (2006) studied yield loss due to biotic stress (insects, diseases, viruses and other organisms) through meta-analysis. In another study, the yield decrease for rice was reported to be 34% of the field yield in tropical Asian regions (Savary et al., 2012).

Peng et al. (2008; 2009) evaluated the yield limitations of paddy fields in China. They showed that most limitations were the result of poor irrigation regimes, incorrect agricultural management, and overuse of pesticides and chemical fertilizers. The yield potential reported for rice differs depending on the cultivar and environmental conditions. For instance, the yield potential of rice for the direct cultivation of seeds in America (Epse et al., 2016) was much less than that of rice (20.1 t ha$^{-1}$) reported by Sheehy and Mitchell (2015) for a dwarf cultivar in a semi-tropical region with a growing period of 168 days. Nonetheless, the estimated potential yield in Epse et al. (2016) was higher than that calculated based on the maximum average paddy yield in a similar climate (Mueller et al., 2012; Foley et al., 2011). Unlike previous studies (Licker et al., 2010; Mueller et al., 2012; Foley et al., 2011), Epse et al. (2016) analyzed paddy yield and reported that it is impossible to obtain 100% attainable yield (potential yield). Moreover, the yield gap varies in different regions and years based on the diversity of pests and climate phenomena (Lobell et al., 2009). Other researchers reported that using improved cultivars of rice, soil fertility management, weed management and irrigation were important in increasing the attainable yield in China in the past decades (Huang et al., 2008). Therefore, analyzing the yield gap to help determine the attainable yield due to improved technologies is necessary (Nhamo et al., 2014). Although it is useful to calculate attainable yields in a particular region - taking into account the best combination of genotypes, environmental conditions and management (G×E×M) - it is not possible to entirely eliminate biotic and abiotic stress during the plant growth period (van Ittersum et al., 2013). Therefore, these functions are insufficient estimates of regional potential with regard to the prevailing climatic and soil conditions. Certain regional climatic factors can also reduce maximum yields.

## CONCLUSIONS

Understanding yield-limiting traits can help researchers reduce yield gap, a key step in increasing yield and sustainability. In present study, the higher yield gap is related to nitrogen usage after flowering, followed by potassium usage, rice cover-crop, fallow, crop rotation, top-dressing frequency, seed usage and planting date. As the calculated yield potential is reached based on actual data in each paddy field, the yield potential is attainable.

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