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ARTICLE

FACTORS LIMITING CANOLA YIELD AND DETERMINING THEIR OPTIMUM RANGE BY BOUNDARY LINE ANALYSIS

Payam Abravan[1], Afshin Soltani[2], Majid Majidian[1,*], Gholamreza Mohsenabadi[1]
[1]*Dept of Agronomy and Plant Breeding, Faculty of Agricultural Sciences, University of Guilan, Rasht, IRAN*
[2]*Dept of Agronomy, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, IRAN*

ABSTRACT

Golestan Province, especially its eastern parts, is a main canola (*Brassica napus*) growing region in Iran. Inappropriate yield is the main factor limiting its planting area. So, factors affecting canola yield were studied in a survey in 2013-2014 and 2014-2015 growing seasons in eastern part of Golestan Province, including Qonbad, Kalaleh and Galikash, in which all managerial data of 332 canola farms were collected and then, were analyzed by boundary line approach. It was found that there was 59% gap between farmers' mean yield (1417 kg ha^{-1}) and potential yield (3407 kg ha^{-1}) which is equal to a yield gap was 1987 kg ha^{-1}. Examining fertilization rates by boundary line analysis indicated that most farms did not fertilize their canola crops adequately. In fact, 80, 93, 95 and 93% of farmers applied less-than-optimum rates of nitrogen, phosphorus, potash, and sulfur fertilizers, respectively. The minimum optimal rates found by boundary line analysis were estimated to be 122 kg ha^{-1} N,49 kg ha^{-1} P_2O_5, 34 kg ha^{-1} K_2O, and 40 kg ha^{-1} S.Also, it was revealed that it would be better to use 42 kg $ha^{-1}$of 122 kg ha^{-1} N as basal fertilizer. Plant density and sowing dates were two other factors limiting yield. The best plant density was estimated to be 83-90 plants ha^{-1} whilst only 23% of farms had densities in this range. The best sowing date range was estimated to be October 27 to November 8. In order to obtain potential yield, the weed population should be less than three plants m^{-2} and the plants showing advanced symptoms of disease in their stem should be less than 4% of the plants. Using findings of the study it is possible to narrow yield gap. The approach can be applied in other regions and crops.
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KEY WORDS
Yield gap, Boundary line model, Potential yield

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***Corresponding Author**
Email:
ma_majidian@guilan.ac.ir

INTRODUCTION

Golestan Province, especially its eastern parts, is one of the most important canola (*Brassica napus*) production regions in Iran, where canola is often produced in rotation with wheat. Canola is considered as a good rotation crop for wheat yield stability. The advantages of canola rotation include its deep root system and the increased porosity of subsoil on the one hand [1] and its capability in breaking the cycle of wheat diseases and weeds on the other hand [2]. Despite the fact that wheat planting area is annually about 400,000 ha in GolestanProvince, canola planting area annually averages only about 30,000 ha and so, it has not gained its real niche in local agricultural pattern. After 2004-2005 growing season when planting area was culminated to 70,000 ha, it was started to decline due to declining yield. Yield and production limiting factors need to be well understood if canola yield is intended to be increased so much that its economical advantages encourage farmers to grow it. Then, the optimum range can be determined for each factor to pave the way for yield improvement.

A lot of factors affect canola production and yield in all regions, including high temperatures [3] diseases especially blackleg (*Leptosphaeriamaculans*) and white mold (*sclerotiniasclerotiorum*) [4] and soil, climatic and managerial factors [2] that are the main natural limiting factors of canola growth and yield.
The present survey was aimed at examining some canola yield limiting managerial factors, including nitrogen, phosphorus, potash, and sulfur fertilization, plant density, and sowing date, investigating the impact of weeds and diseases on yield, and determining their optimum range by boundary line analysis. Boundary line analysis is a technique by which the yield response to an environmental or managerial factor can be quantified under the conditions that all other factors are variable. In fact, this technique specifies yield response to a specific factor under the conditions that all other factors are suitable [5]. Since natural conditions are constantly changing and natural factors are uncontrollable and unpredictable, the results might be affected and the precise evaluation of the relationship between two variables might be impossible [6]. So, an approach that could cope with these problems would be invaluable. Boundary line approach, first introduced by [7] possessed this feature. The technique was successfully used to describe the relationship between soil nutrient concentrations and soybean yield [8] and the leaf yield of are canut [9] to determine the relationship between yield and plant density of corn as well as some soil characteristics [10] to estimate the range of N_2O emission from soil [11] to specify the relationship between pea yield components [12] and in studies on wheat yield gap [13] and soybean yield gap [14].

Since yield is affected by various factors, the use of boundary line technique will allow recognizing the yield response to just one variable out of the various collected data. Rather than fitting regression lines from the middle of data dispersions, the technique studies the upper edge of the data dispersion. This boundary shows the highest obtained yields (yield potential) and/or the best yield as affected by different levels of a certain factor or input. The technique assumes that these yields are the highest yields possible in the absence of other limiting factors and that all points located at lower spots are limited by other factors.

MATERIALS AND METHODS

Surveyed region

The surveyed region was located to the east of Golestan Province around Qonbad, Kalaleh and Galikashcitiescovering the area between the latitudes of 37°02'50" and 38°05'29" N. and the longitudes of 54°33'01" and 56°02'01" E. The highest altitude of the surveyed region was 500 m. Qonbad has 159,000 ha arable land, out of which over 52% is rain-fed. Kalaleh is to the east of Golestan Province bordered Qonbad. It has 68,000 ha arable land, 80% under rain-fed. Galikash is bordered to the north of Kalaleh and Qonbad. Its area is 1460 km2 with 29,000 ha arable land, out of which about 56% can be irrigated.

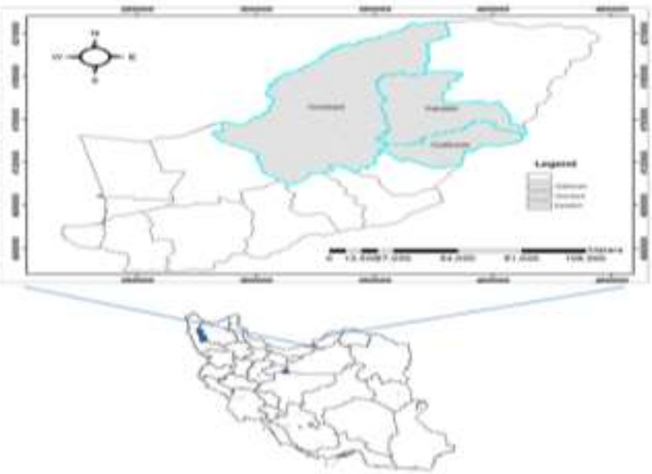

Fig. 1: The location of survey region in eastern Golestan Province, Iran

The surveyed region has Mediterranean climate with dry summers. Table 1 shows local climatic data.

Table 1a: Growing season climate data of Kalaleh

Date	Mean T_{min}		Mean T_{max}		Rainfall (mm)		Evaporation (mm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
October	12.9	12.5	26.3	24.9	45.1	26	120.9	130.7
November	10.6	7.3	21.4	17.1	34.2	63.9	69.7	58.7
December	3	4.6	12.9	16.8	49.9	29.5	40.6	50.5
January	2.9	3.2	13.3	14	27.6	43.1	51.1	51.4
February	-0.4	5.6	12.9	14.8	33.7	90.9	37.3	39
March	5.2	5.7	17.4	15.6	84.3	72.8	78	62.6
April	10.1	9.4	24.1	23.1	20.1	22.4	96.6	96.1
May	16.3	15.3	32.5	30.5	19.4	13.4	24.3	194.5

Source: Kalaleh synoptic station

Table 1b: Growing season climate data of Gonbad

Date	Mean T_{min}		Mean T_{max}		Rainfall (mm)		Evaporation (mm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
October	13.6	12.7	26.5	25.6	43.4	31.8	95.3	88.2
November	10.8	7.6	21.4	17.7	43	54.3	47.3	36
December	2.7	4.4	13	16.4	34.9	28.4	21.7	29
January	2.7	2.8	13.9	14.3	12.9	39.7	28.8	30.7
February	-0.5	6.4	13.1	15	28	50.3	34.9	29.7
March	5.7	5.9	17.1	16.5	92.6	56	52.7	47.4
April	10.6	9.3	23.9	24.2	14.9	15.5	79	90.6
May	17.2	15.9	33.1	32	15	3.3	177.3	183.2

Source: Gonbad synoptic station

Data collection

The survey was carried out in the eastern part of Golestan Province in Qonbad, Kalaleh and Galikash in 2013-2014 growing seasons. In each growing season, more than 60 canola farms were surveyed in each region. The survey just considered the impact of the managerial factors, ignoring soil and plant-related data. The collected data were related to the managerial practices including field preparation, agronomical pattern like rotation, planting data, cultivar, and pests, diseases and weeds.

Boundary line analysis

The scatter diagram of the yield data of 332 farms as dependent variable was drawn against managerial variables as independent variables. Boundary line analysis (BLA) is based on the premise that the line fitted on the outer edge of data body (boundary line) is indeed the variable function of the independent variables [15]. It is assumed that such a line is an independent function and is only limited by a single dependent variable or factor. Thus, keeping these facts in mind, all other points under this line (lower yields) have been influenced by other limiting factors [15].

The scatter diagram of data was drawn between dependent variable of seed yield in 332 canola farms and N, P, K and S fertilizer application. First, outlier data were removed and then, points appropriate for boundary line fitting on upper edge of data were selected that had more or less same distance to *x*-axis. The same procedure was repeated for independent variables of plant density and planting date. Among other factors affecting canola yield, two variables of weeds density and diseased plants percentage were also studied and the boundary line was fitted on distribution of yield data as influenced by these factors. In the present study, after drawing the scatter diagram of the yield in each farm as dependent variable against independent variables (agronomical managements), a function was fitted on upper edge of data distribution by SAS Software Package and nlin procedure. If the functions resulted from the fitting of the boundary line against these points were polynomial, they would be fitted as two-piece functions or, if required, as three-piece functions to better describe the ascending or descending relationship of dependent and independent variables and to determine the optimum range. Then, the optimum range was determined for each factor and the yield gap was calculated by boundary lines equations.

RESULTS

Nutrients and fertilizers

Among 332 surveyed farms in two years of the study, the lowest yield was 200 kg ha^{-1} and the highest yield was 3450 kg ha^{-1}. The distribution of yield data against managerial variables of fertilization showed that the response of yield as dependent variable to the application of main nutrients as independent variables exhibited similar function so that the application rate of N, base N, P_2O_5, K_2O and S followed a two-piece function [Fig. 2].

The resulted two-piece function [Fig. 2a] shows that if N fertilizer is not applied, seed yield will not reach even 1 t ha^{-1} (928 kg ha^{-1} was the maximum yield under no N fertilizer). Also, fitted boundary line reveals that the highest possible yield is obtained by the application of at least 122 kg pure nitrogen. In this respect, the maximum limited N yield was estimated to be 3425 kg ha^{-1} [Table 2]. Whilst the minimum optimum rate for pure nitrogen fertilizer was 122 kg ha^{-1}, 80% of farmers applied lower N rates to their canola farms so that mean N rate was 92 kg ha^{-1} in surveyed farms [Table 3]. Also, in spite of the fact that the application of 48 kg ha^{-1} pure N as basal resulted in the yield of 3407 kg ha^{-1} [Fig. 2b], 93% of the surveyed farmers used lower rates of basal N fertilizer [Table 2]. In addition, although N rate varied in the range of 0-250 kg ha^{-1} pure N, its mean application rate was only 10.5 kg ha^{-1} [Table 3].

Nitrogen is an important nutrient for canola playing a crucial role in boosting its yield. The number of branch per plant, the number of pods per plant, plant height, and biological yield are increased by N application [16]. Bahmanyar and Poshtmasari (2010) reported that the highest yield was obtained from the treatment of 150 and 225 kg N ha^{-1} and that canola's response to the increase in N rate varied with environmental factors, climate, and soil type. The application of N fertilizer influenced seed yield in all surveyed regions significantly. Probability levels were $P < 0.0001$, $P < 0.0001$, and $P < 0.0001$ and the root of mean squares of error (RMSE) were 487, 504, and 535 kg ha^{-1} for Qonbad, Kalaleh and Galikash, respectively. The slope of boundary line [Fig. 1a] shows that seed yield could be increased by 20.4 kg ha^{-1} per 1 kg ha^{-1} increase in N rate up to N level of 122 kg ha^{-1}. Since 80% of farmers applied less-than-optimum rates of nitrogen (122 kg ha^{-1}) and 93% of them no use basal N fertilizeror appliedless-than-optimum rates (48 kg ha^{-1}), it can be concluded that lower dose of N application is one of the most important limiting factors of growth and production in the studied region.

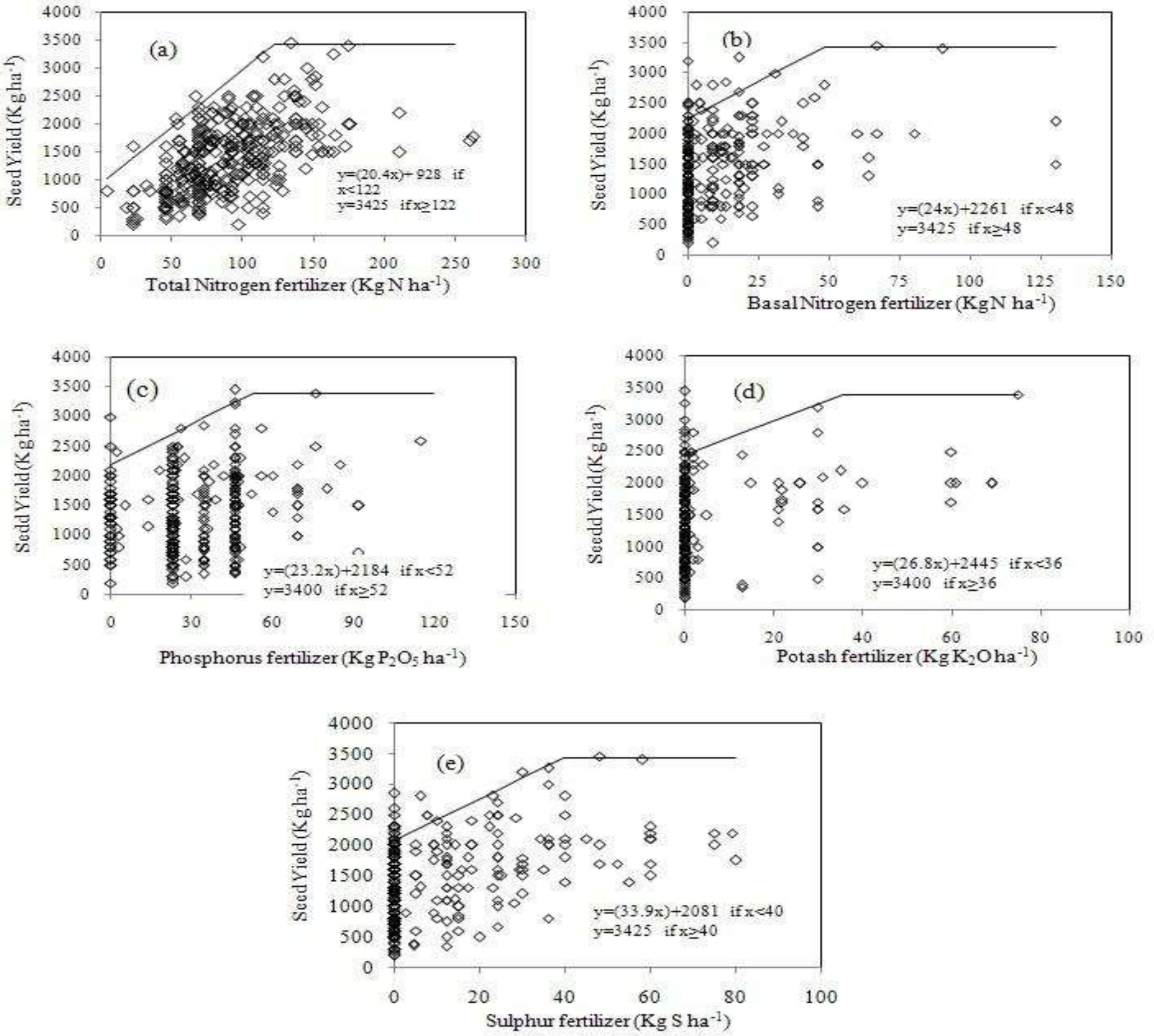

Fig. 2: Scatter graph of the yield data against the rate of nitrogen (N) (a), basal N (b), phosphorus (c), potash (d), and Sulfur (e) fertilizers as well as the fitted boundary line

Table 2: The results of boundary line analysis as well as estimated potential yield and yield gap of canola in eastern parts of Golestan Province

	BasalN (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Sulfur (kg ha^{-1})	Density (plants m^{-2})	Sowing date	Disease (%)	Weeds (plants m^{-2})	Average
Minimum optimal level	48	122	52	36	40	83-90	36-48	<4	<3	-
Farmers out of optimum (%)	93	80	93	96	92	77	56	90	66	-
Yield at optima (kg ha^{-1})	3425	3425	3400	3400	3425	3279	3425	3450	3450	3407
Average yield (kg ha^{-1})	1417	1417	1417	1417	1417	1417	1417	1417	1417	1417
Yield gap (kg ha^{-1})	2008	2008	1983	1983	2008	1862	2008	2033	2033	1990
Yield gap (%)	59	59	58	58	59	57	59	59	59	58

Table 3: Management range of yield limiting factors in the surveyed farms

	BasalN (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Sulfur (kg ha^{-1})	Density (plants m^{-2})	Sowing date	Disease (%)	Weeds (plants m^{-2})
Minimum	0	4.5	0	0	0	33	282	0	0
Average	10.5	92	32.2	5.4	9.7	78	310	6.2	4
Maximum	250	365	190	170	200	113	355	16	26

The minimum optimal rates were lower for P and K (52 and 36 kg ha^{-1} absorbable P and K, respectively). The application of these two nutrients had positive impact on yield. Higher P and N application rates improved canola yield significantly through enhancing the number of pods per plant and the number of seeds per podas reported by [17] who stated that 60 kg P_2O_5 ha^{-1} gave rise to the best result. Whilst most farms (85%) were fertilized with P, only 8.5% of them were treated with K fertilizers. Nonetheless, potassium is an important nutrient that plays a vital role in assimilates mobilization and the tolerance of stresses. Figure 2c depicts that, at most, a yield of 2 t ha^{-1} can be obtained without phosphorus application. However, a yield of 3400 kg ha^{-1} can be produced by the application of 49 kg ha^{-1} phosphorus. In the surveyed regions, 93% of farmers used unfavorable rates of phosphorus [Table 2]. Potash fertilizer was, also, applied in only 26 farms, i.e. 8.5% of all surveyed farms.Figure 2d shows that the application of 36 kg k_2O ha^{-1} resulted in the yield of 3400 kg ha^{-1}. Although some farms had been applied with as high as 170 kg k_2O ha^{-1}, the mean application rate was very slight in the surveyed region [Table 3]. Table 2 reveals that 95% of the farms received unfavorable potash fertilizer.

Sulfur is another important nutrient for the growth and yield of canola so that its application improves plant height, branch number, pod number per plant, seed number per pod, and biological and seed yield [18]. It influenced yield in the present study, too. In eastern parts of the province, mean yield in farms treated with sulfur was 1763 kg ha^{-1}, whilst it was only 1239 kg ha^{-1} in farms that were not. According to Figure 2e, the application of at least 40 kg S ha^{-1} made it possible to obtain a yield of 3425 kg ha^{-1}. At the same time, Table 2 indicates that the rate of S application was lower in 92% of the farms. In total, about half of the farms were not treated with sulfur fertilizer. About one-third (34%) of farmers used S fertilizer with average application rate of 10 kg ha^{-1} in eastern parts of the studied province [Table 3].

Sowing date

Delayed planting reduced both seed yield and oil yield so that two weeks delay in planting resulted in 309 kg ha^{-1}loss of yield (i.e. almost 22 kg ha^{-1} d^{-1}) [19]. They related the yield loss to the coincidence of flowering with higher temperatures. They found that the yield loss was 289 kg ha^{-1} for each °C higher temperature. Canola farms were planted in early-October to mid-December in the surveyed region. In fact, half of the farms were not planted in the sowing interval (October 6 to November 10) recommended by research centers. Boundary line analysis showed that the optimum range for sowing date was October 27 to November 8 in the surveyed region. It implies that canola should be sown in this interval in order to produce the maximum yield. Figure 3a shows that the boundary line fitted on the upper edge of data is a three-piece function. The yield will be 3425 kg ha^{-1} if the sowing is carried out in the optimum interval. Table 2 indicates that 56% of the farms were not sown in this sowing interval. The sowing dates varied in the range of October 9 to December 21 in the surveyed region. However, a lot of farmers planted their farms in the optimum range, so that the mean sowing date was early-November [Table 3]. The yields in farms sown before or after optimum sowing range were lower than those in farms sown within this range, ignoring all other limitations. In early-sown farms, pests and birds reduce plant density. Also, weeds spread faster creating more intense competition. Flowering and seed filling period coincides with higher temperatures in late-sown farms affecting yield. Also, precipitation survey shows that reproductive phase coincides with drier conditions in late-sown farms [Table 1].

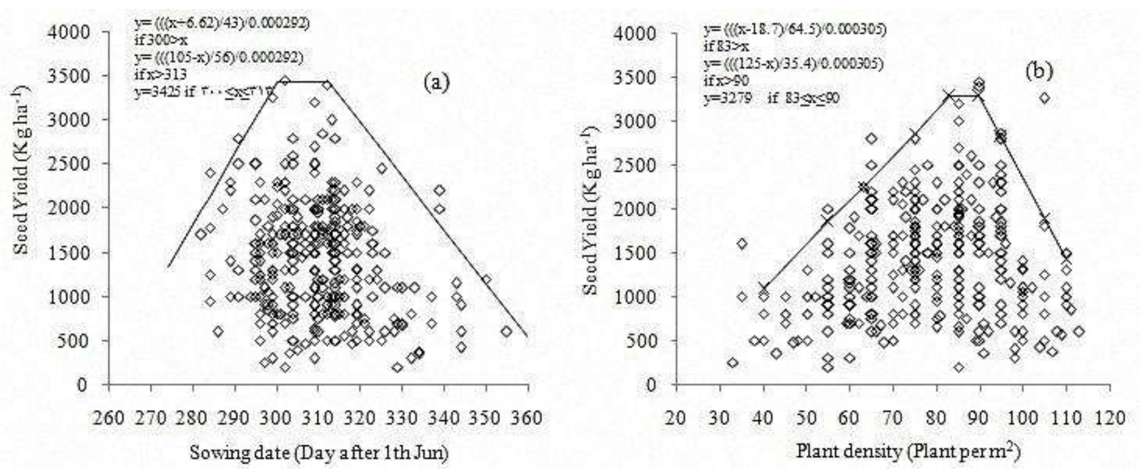

Fig. 3: Scatter graph of yield against sowing date (a) and plant density (b) as well as fitted boundary line

Plant density

Canola yield is widely affected by agronomical pattern, sowing method and plant density [20]. The increase in density only up to optimum level improves yield. Boundary line analysis determined optimum plant density as 83-90 plants m^{-2}. Due to the fact that no herbicides were optimally applied and since the planted cultivars were not of those resistant to general herbicides and no pre-planting herbicides were applied, weeds used space fast in lower plant densities and reduced yield by creating competition. Sounder similar conditions, optimum plant density is higher for maximum yield than that in other parts of the world.At densities higher than 90 plants m^{-2} in addition to the increased elongation of the stems, the stems become weaker increasing the possibility of the lodging of the plants and the outbreak of diseases. Also, higher inter-species competition reduced the availability of the resources affecting yield. Plant density varied in the range of 33-113 plants m^{-2} in the surveyed farms [Table 3]. As can be seen in Figure 3b, boundary line had three-piece trend. Optimum density was found to be 83-90 plants m^{-2} for maximum yield of 3279 kg ha^{-1} [Fig. 3b]. Table 2 indicates that 77% of farms had out-of-rangethose plant densities.

Diseases and weeds

The main diseases in the surveyed regions were blackleg (*Leptosphaeriamaculans*) and white mold (*Sclerotiniasclerotiorum*), and mean infection in surveyed canola farms was a little higher than 6% [Table 3]. These two diseases are the main diseases of canola in other parts of the world [4 and 21]. However, the yield loss in infected regions can be reduced to as low as 10-15% by using genetic resistance, keeping distance from the residue of previous crop, and applying fungicides [21]. [2] observed infection in as high as 40% of plants in wetter regions with lower fungicide application. The fitting of a boundary line on upper edge of yield data revealed that yield response to the diseases incidence percentage and weeds population followed a two-piece function. Less than 4% infection of plants to the disease was the optimum level for maximum yield of 3450 kg ha^{-1} [Fig 4a]. Since the planted cultivars were not genetically resistant to the diseases, the incidence rate was higher and 90% of farms showed symptoms of over 4% infection rate [Table 2].

Regression relationship between seed yield and infection percentage was significant for Kalaleh farms at the probability level of $Pr < 0.0005$ and for Galikash farms at the probability level of $Pr < 0.0001$, whilst only 11 and 18% of yield variations was accounted for by disease infection in Kalaleh and Galikash, respectively. According to the slope of regression equation inside yield data against plants infection percentage in Kalaleh and Galikash, where there was a high disease incidence rate, the yield loss was, on average, 67 kg ha^{-1} for each percent increase in disease infection. When boundary line analysis was used for whole region, the regression equation showed 184 kg loss of potential yield for each percent increase in disease infection.

It implies that ignoring all other limitations, the yield loss caused by the outbreak of diseases plays an important role in the reduction of potential yield.The rate of blackleg incidences was increased with delayed sowing [4]. They used regression analysis to find the possible relationship between yield and the damages of *Sclerotinia*and found that blackleg and white mold, individually or together, reduced yield by 0.39-1.54 t ha^{-1} and that the lower the infection was, the higher the yield was significantly. Also, they reported that for each percent decrease in blackleg infection, the yield was increased by 5% while it was 1.3% for *Sclerotiniasclerotiorum*.

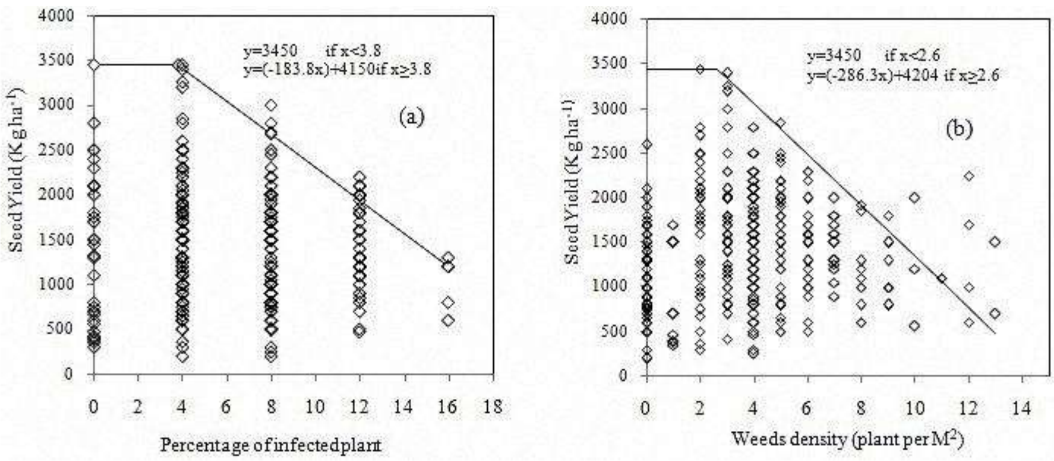

Fig. 4: Scatter graph of yield against infected plants percentage (a) and weeds density (b) as well as fitted boundary line

The function of yield response to weeds population indicated that the maximum yield of 3450 kg ha^{-1} can be obtained from weeds population of less than three plants m^{-2} [Fig. 4b]. Since the cultivars were not resistant to general herbicides and no pre-planting herbicides were applied, 66% of the surveyed farms were attacked by a high population of weeds [Table 2]. Weeds reduce crop yield by competing with the crop. The damage of weeds from the family of canola to this crop yield is reported to be 11-16% under weed population of 4-7 plants m^{-2} [4]. Seven wild mustards, nine wild spear thistles, twelve wild oats, and four wheat and barleys per unit area can result in 16, 14, 10, and 11% loss of canola yield [23]. According to boundary line analysis, canola can tolerate at most three weed plants m^{-2} to produce the maximum yield under the conditions of the present survey and higher weed populations can reduce potential yield with a relatively high slope (-286 kg ha^{-1} per weed plant) [Fig. 3b].

CONCLUSION

Some factors limiting canola yield were surveyed in eastern part of GolestanProvince by boundary line approach and the yield gap caused by each factor was estimated. Whilst mean yield produced by farmers was 1417 kg ha^{-1} seed, the obtainable yield was estimated to be 3407 kg ha^{-1}, implying a yield gap of 1987 kg ha^{-1}. This is, in fact, the gap between local farmers' mean yield and the optimum yield estimated by boundary line analysis. It came to be known that most farms were not adequately fertilized. In the surveyed region, 80, 93, 95, and 93% of farmers were using non-optimum rates of nitrogen, phosphorus, potash, and sulfur fertilizers, respectively. The optimum rates of fertilizers that can be recommended to reduce or eliminate yield gap caused by inadequate fertilization were estimated to be 122 kg ha^{-1} N, 49 kg ha^{-1} P_2O_5, 34 kg ha^{-1} K_2O, and 40 kg ha^{-1} S. Furthermore, it was found that it would be better to use 42 kg $ha^{-1}$of 122 kg ha^{-1} N as base fertilizer. The best plant density was estimated to be 83-90 plants ha^{-1}, and only 23% of the surveyed farms were in this plant density range. The best sowing date range was October 27 to November 8. Also, the population of weeds should be less than three plants m^{-2} and the density of diseased plants should be less than 4% in order to obtain maximum yield.

CONFLICT OF INTEREST

There is no conflict of interest

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None

FINANCIAL DISCLOSURE

None

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