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Modeling Vegetative Stage Response of Canola (*Brassica napus* L.) to Combined Salinity and Boron tresses

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Abstract

Boron (B) is essential to growth at low concentrations and limits growth and yield when in excess. Little is known regarding plant response to excess B and salinity occurring simultaneously. In this study, two models of Leibig-Sprengel (LS) and Mitscherlich-Baule (MB), originally proposed to explain plant response to nutrients only, were modified to evaluate canola yield response to combined levels of B and salinity stresses. The water salinity treatments were consisted of non-saline water, 3, 6, 9 and 12 dS m^{-1}. The B treatments were 0, 10, 20 and 30 mg kg^{-1} added to soil as H_3BO_3. It was revealed that modified LS model can satisfactorily predict canola dry matter yield. The calculated statistics: Maximum Error, Root Mean Square Error, Modeling Efficiency, Coefficient of Determination and Coefficient of Residual Mass, indicated that the estimated relative dry matter yield for soil B concentrations and salinity levels by modified LS model compared to modified MB model was closer to the measured relative yield. Therefore, the use of modified LS model for estimating canola relative yield in salinity and B stresses is recommended. The threshold value of salinity increased with higher B concentration and maximum dry matter yields decreased with increasing B concentration. Excess B was found to decrease dry matter yield of canola. This effect was inhibited when plants were exposed to simultaneous B and salinity stresses. Both irrigation water salinity and B concentration influenced water use efficiency (WUE) of plant, however, only B concenteration influenced canola yield in in the same manner.

Keywords: Leibig-Sprengel (LS); Mitscherlich-Baule (MB); Relative dry matter yield; Water use efficiency (WUE)

Introduction

Boron (B) is an essential nutrient element for plant growth. In many parts of the world natural B concentrations are insufficient for potential production and B is therefore applied as fertilizer in agricultural fields (Gupta *et al.*, 1985). However, B in soil and irrigation water can reach concentrations which are toxic to plants. B is essential for all plants at certain low concentrations and becomes toxic for many plants at concentrations which can be found in natural and agricultural situations (Eaton, 1944; El-Motaium *et al.*, 1994; Keren and Bingham, 1985; Maas, 1990; Tsadalis, 1997). B is often found in high concentrations in agricultural farms in arid and semi-arid regions where saline soils and waters are exist. Municipal and other wastewater effluents used for irrigation are also sources of excess B in agricultural soils (Tsadilis, 1997). Plants yield is usually reduced as concentrations of B in plant increases (Eaton, 1944; Francois, 1984). Toxic responses to B for sensitive plants under field conditions are reported when plant tissue B was more than 18.5 μg g^{-1} dry weights (Gupta *et al.*, 1985). Most studies on B crop tolerance are based on occurrence of B injury and not on yield reduction. Francois (1984) found that visual symptoms of B toxicity appeared at soil concentrations lower than the yield threshold values. Bingham *et al.* (1985) have tested the Maas–Hoffman salinity model (Maas and Hoffman, 1977) for B toxicity and found threshold values and relative grain yield decrease in relation to B concentration in nutrient solution for wheat, barley and sorghum. Bingham and Colleges (1985) did not find any association between salinity tolerance and B tolerance but found a relation between increased leaf B concentration and decreased grain yield. Only few investigations have been conducted to interactive effects of B toxicity and soil salinity (Ben-Gal and Shani, 2002). Shani and Hanks (1993) found that B affected corn and barley yields but did not significantly reduce transpiration. Although they modeled B toxicity, salinity, and drought stress based on independent cumulative effects, but one has to be careful with any generalizations. Increased ionic strength causes clay mineral platelets to separate and to increase surface charges at their edges thus providing for greater B adsorption. B toxicity resulting from irrigation water that is high in both B and salts may take longer to occur and it occurs with less extent than with water having high B and less salts. Gratten and Colleges (1997) found that at low salinity levels, B applied at high levels (2.3–2.8 mol m^{-3}) to eucalyptus trees caused biomass reduction and B toxicity symptoms but this did not occur at high salinity levels (ECw > 10 dS m^{-1}). In a study with 42 different crops irrigated with high salinity (EC = 8.2 dS m^{-1}) and B (1.57 mol m^{-3}) concentration, Ferreyra and Colleges (1997) found that various crops can produce higher yields than what is expected from the published information. They reach the conclusion that effects of salinity and B on crops are not necessarily additive. El-Motaium and Colleges (1994) found that high salinity reduced B uptake and toxicity symptoms in *Prunus* rootstocks and suggested a possible interaction between B uptake and sulfate ion concentration.

Crops are frequently exposed to more than one factor that might affect growth. Knowledge on appropriately calculating the effects of multiple stresses on the ultimate crop yield is important. There are two basic approaches to evaluating the effects of multiple stresses. One is that the yield will be affected by the stress that most limits growth. This is so called “law of the minimum”. This law, also, has been called Liebig–Sprengel model. The Liebig–Sprengel model (LS model), suggests that at any given time a single growth factor i.e., the most limiting one, determines plant yield. Thus, the crop response to this single factor has a linear trend. As many factors are involved in plant growth, the LS approach results in a stepwise ‘constant returns’ response curve (Black, 1993; Van der Ploeg *et al.*, 1999). The other approach is that the relative effects of each stress are multiplied to determine the final growth. This approach has suggested by Mitscherlich and Baule. Mitscherlich (1909) and proposed the concept of diminishing plant response (Black, 1993). The biological basis of this model can be related to saturation of the root carrier-mediated uptake system. Were Mitscherlich-type growing factors that simultaneously influence plant growth and do not interact with each other was proposed by Baule in 1918 to act additively (Stewart, 1932). The combined Mitschelich–Baule approach is denoted MB hereafter. Some other combined response curves in cases of having synergistic or antagonistic interactions between the growth factors, are well described by Black (1993) and Lark (1997). The combined MB-type response model implies that if five growing factors, out of the 35 mentioned by Wallace (1990), are in mild shortage, each at 90% of its optimal level, and one growing factor is at 80% of its optimal level, then only 0.47 of the maximum yield ($Y_{\max}$) is expected ($Y = Y_{\max} \times 0.9^5 \times 0.8$) (Shenker *et al.*, 2003). In contrast, the LS model would predict 0.8 of the maximum yield for the same case. Similarly, if antagonism versus no interactions between B and salinity is assumed, higher B concentration in soil or water will be neglected at increasing salinity level if antagonism is assumed, while if no interaction rules are exist the response curve and salinity is a LS-type limiting factor, increased B concentration in soil or water will limit yield. The LS model for the case of salinity and B is defined as (Ben-Gal and Shani, 2002):

$$y_r = min\begin{cases} \begin{cases} 1 & ;\ EC < EC_{cr} \\ 1-b.\left(EC-EC_{cr}\right) & ;\ EC \geq EC_{cr} \end{cases} \\ \begin{cases} 1-n.\left(B-B_{cr}\right) & ;\ B \geq B_{cr} \\ 1 & ;\ B < B_{cr} \end{cases} \end{cases} \tag{1}$$

n is the slope of the yield response to B where salinity is negligible, ***b*** is slope of the yield response to salinity where B effect is negligible, and $\boldsymbol{EC_{cr}}$ and $\boldsymbol{B_{cr}}$ are salinity and B threshold for yield reduction, respectively. $\boldsymbol{y_r}$ is relative yield. The estimated maximum relative yield, $\boldsymbol{Y_m}$, is defined for the case in which B and salinity do not limit plant growth. The parameters *n*, *b*, B_{cr} and EC_{cr} are plant specific. The MB model for the salinity and P factors is described by (Ben-Gal and Shani, 2002):

$$y_r = \frac{y}{y_{max}} = (1-e^{c_B(B-B_{max})}).(1-e^{c_{EC}(EC-EC_{max})}) \tag{2}$$

Where c_B and c_{EC} are the Mitscherlich coefficients for B and salinity, respectively, and the subscript max denotes levels of EC or B that cause plant death or zero yield. y and y_{max} are dry matter yield and maximum dry matter yield, respectively.

The objectives of the study were to evaluate and model canola dry matter yield based on relationship between B concentration and water salinity, and to estimate the yield response of canola plants to the combined effects of these factors over a wide range of B and salinity levels.

Material and method

Experimental set-up

Plant-response studies were conducted on canola receiving B through soil and were irrigated with natural saline water. Experiments were conducted under greenhouse condition at the Soil and Water Research Institute, Tehran, Iran (51,404'; 35,702'). Sixty pots with 15-L capacity each were filled with Qom sandy loam soil (Coarse-loamy mixed thermic Calcic Haplosalids). Soil properties are shown in Table 1. The effect of salinity and B was investigated by combining five salinity levels through irrigation water and four B levels in the soil with three replications. Salinity was brought to EC of 0.3 (EC_1), 3 (EC_2), 6 (EC_3), 9 (EC_4), and 12 (EC_5) dSm^{-1} by diluting the water of Qom Lake (50,811'; 34,465'). Water properties are shown in Table 2. Treatments of B rates were set as 0 (B_1), 10 (B_2), 20 (B_3) and 30 (B_4) mg B kg^{-1} soil. B was added to the soil as boric acid (H_3BO_3) before planting. Other nutrients for plant growth were added to soil based on Soil and Water Research Institute (SWRI) recommendation for canola plant (Khadami *et al.*, 2000). Canola (*Brassica napus* L., cv. Hayola 401) was planted in the pots and irrigated initially for 2 weeks using water with EC =0.3 dS m^{-1}. Salinity treatments were started two weeks after germination. Experiments were started with four plants per pot and thinned to two plants after 20 days. Nitrogen (N) and potassium (K) were applied as commercial urea and K_2SO_4 fertilizers through the irrigation water at the recommended levels. Each pot incorporated a 5-cm highly conductive sand drain to ensure proper soil aeration at the pot bottom. Water draining through the pots was analyzed daily for EC and weighed during the growing period. A continuous water and salt balance was recorded for each pot and water uptake was evaluated from the running water balance. The surface of pots covered with gravel to decrease evaporation. In order to calculate evaporation, some control pots (with no plants) were placed among the planted pots. Daily water balance generated evapotranspiration (ET) data for each pot during the growing period. Calculations of ET was set by using the equation $ET = I - Dr \pm \theta \cdot Z$ where I is irrigation, Dr is drainage, θ is the change in volumetric soil water content, and Z is the pot depth. The leaching fraction (LF) was 0.5 in the experiment to ensure enough leaching and prevent accumulation of salt in root medium. The position of pots was changed in the greenhouse to ensure uniform climatic conditions. The plants were harvested 60 days after germination; washed with deionized water, and ground. Its total B was measured by the azomethine-H method (Gupta and Stewart, 1975; Page *et al.* 1982). Boron in soil and water samples was determined by the same method. Soluble ions including Na, Ca, Mg, and Cl were determined by atomic absorption spectrometry and titration methods (Page *et al.*, 1982).

Table 1. Selected properties of soil used in this study.

pH	EC ($dS\ m^{-1}$)	SO_4^{2-} ($mgkg^{-1}$)	OC (%)	P ($mgkg^{-1}$)	Cl^- ($mgkg^{-1}$)	K^+ ($mg\ kg^{-1}$)	Na^+ ($mgkg^{-1}$)	B ($mg\ kg^{-1}$)	Soil Texture	θ_{FC} (%)
7.9	3	64	0.2	5.3	216	189	409	2.2	SL	15.5

Table 2. Selected properties of applied water before diluting.

pH	EC dS m^{-1}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	K^+ mmol$_c$ L^{-1}	Na^+	B	Mg^{2+}	Ca^{2+}
8.1	196	176	54	5.5	1388	2.9	1313	20	142	128

Parameters of the LS and MB models for salinity or B alone were fitted to data reflecting situations in which only one of the factors predominate yield using the ordinary least square model (Quantitative Micro Software, 1997). Thus, parameters were fitted simultaneously for B, using experimental data of the lowest salinity only, and for EC, using experimental data of the 0 mg B kg^{-1} (control=B_1) soil treatments. The combined experimental effect of the two factors at all tested levels was evaluated using given models (Equations (1) and (2)).

Quantitative comparison of experimental and simulated yield canola

Analysis of residual errors, differences between measured and simulated values, can be used to evaluate model performance. These are maximum error (ME), root mean square error (RMSE), coefficient of determination (CD), modeling efficiency (EF), and coefficient of residual mass (CRM). The mathematical expressions of these statistics are as follows:

$$ME = \max\left|P_i - O_i\right|_{i=1}^{n} \quad (3)$$

$$RMSE = \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}\right]^{\frac{1}{2}} \frac{100}{\overline{O}} \quad (4)$$

$$CD = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2}{\sum_{i=1}^{n}\left(P_i - \overline{O}\right)^2} \quad (5)$$

$$EF = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \quad (6)$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \quad (7)$$

Where P_i are the predicted (simulated) values, Q_i the observed (measured) values, n is the number of samples, and the over lined characters represent the mean values. The lower limit for ME, RMSE, and CD is zero. The maximum value for EF is one. Both EF and CRM can be negative. The ME value represents the worst case performance of the model, while the RMSE value shows how much the simulation overestimates or underestimates the measurements. The CD gives the ratio between the scatter of the simulated values and of the measurements. The EF value compares the simulated values to the averaged measured values. A negative EF value indicates that the averaged measured values give better estimate than the simulated values. The CRM is a measure of the tendency of the model to overestimate or underestimate the measurements. A negative CRM shows a tendency to overestimate. If all simulated and measured data are the same, the statistics yield: ME=0; RMSE=0; CD=1; EF=1; CRM=0 ((Homaee *et al.*, 2002).

Results and discussion

The relative dry matter yield as a function of applied saline water levels for the various B rates is given in Figure 1. By increasing the applied salinity in treatments, the yield of canola were increased at first and then decreased. In general, application of B to soil has decreased the yield at salinity levels. It seems that B is a more limiting factor than salinity. However, applying 10 and 20 mg B kg^{-1} soil increased the relative dry matter yield at salinity of 12 dS m^{-1} in comparison with control treatment. Therefore, applied B decreased salinity effect at high salinity level. Ben-Gal and Shani (2002) reported the antagonistic relationship between salinity and B when excess B combined with high salinity levels. Boron application decrease canola yield at EC = 12 dS m^{-1}. Ferguson and Colleges (2002) reported that Concentrations of B in injured leaf tissue of pistachio rootstocks ranged from 1000 to 2500 mg kg^{-1}. Leaf injury decreased with increasing salinity, although leaf B was not significantly reduced suggesting an internal synergistic interaction between B and other mineral nutrients. However for *P. vera* on *P. integerrima*, the highest level of salinity produced the greatest injury, possibly as a combination of B plus Cl^- and/or Na.

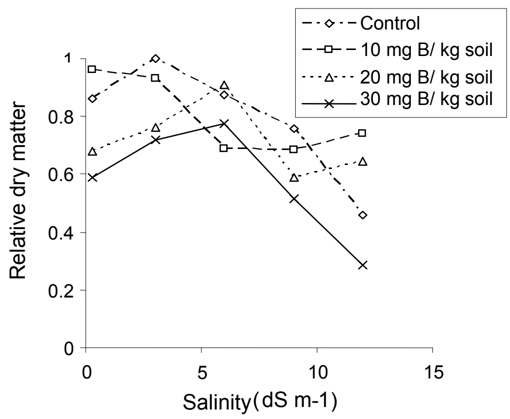

Figure 1. The relative dry matter yield of canola as a function of saline water levels for various boron rates. Each data point represents the mean yield from three replications.

The calculated water use efficiency (WUE), (dry matter yield / transpired water) as a function of salinity is shown in Figure 2. WUE increased with salinity. The effects of salinity on WUE follow different patterns according to the nature of salts. If salinity stress is due to ion toxicity, resulting in increased respiration or decreased in photosynthesis, decreased amount of assimilates (which will be allocated to plant growth per unit transpired water), resulting low WUE (Hester *et al.*, 2001). However, if the stress is a result of decreased osmotic potential, plants respond by stomatal closure. Since photosynthesis is less affected by stomatal conductance than transpiration, WUE is expected to increase with salinity (Brugnoli and jorkman, 1992**;** Ben-Gal and shani*,* 2003). However, agronomic WUE (yield/applied water) will tend to decline with increasing salinity (Gucci *et al.*, 1997).

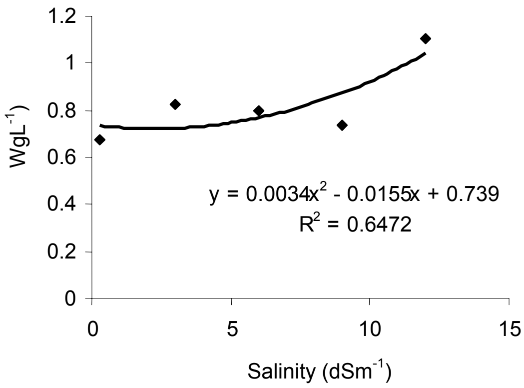

Figure 2. Effect of saline water treatments on water-use efficiency in the production of grain.

Application of 20 and 30 mg B kg^{-1} soil decreased WUE compared to control (Figure 3). The obtained experimental WUE as a function of B provided similar trend as for relative yield-B relation, therefore decreased WUE with applying B is caused by decreasing B on yield.

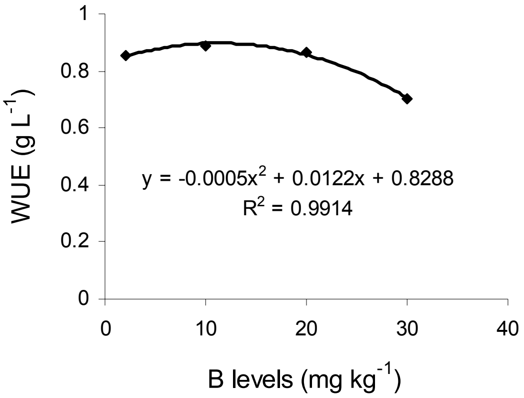

Figure 3. Effect of boron levels on water-use efficiency in the production of grain.

The effect of salinity on B concentration in canola dry matter for various B levels was shown in Figure 4. The B concentration was increased with B application. In general, salinity caused decrement in B concentration. At any B treatment level, plants with higher level of irrigation salinity accumulated less B. Our findings comply with the accepted understanding that B is transported into the plant passively through transpiration as long as B nutrition is not deficient (Dannel *et al.*, 2000; Pfeffer *et al.*, 1999; Raven, 1980).

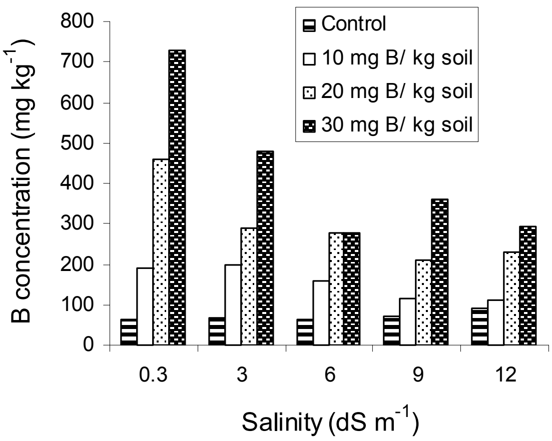

Figure 4. Effect of saline water treatments on B concentration in canola grain for various B levels.

Relative yield is shown as a function of dry matter B content in Figure 5. Salinity levels are denoted by different symbols. At low salinity condition, dry matter yield was reduced linearly with leaf B concentration (RDM = 0.9582 - 0.0005 B, R^2 = 0.81). In general, as irrigation water salinity increased, the correlation between B concentration and dry matter diminished. At EC = 12 dS m^{-1}, B concentrations had no influence on biomass production.

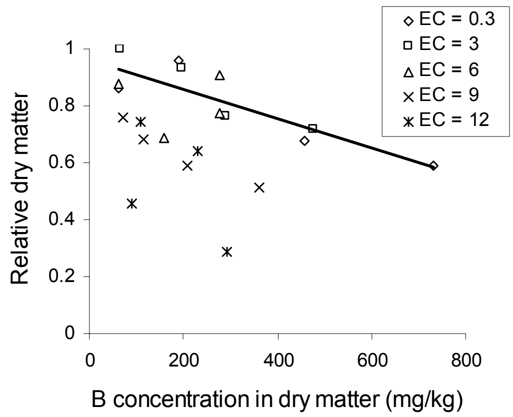

Figure 5. Relationship between boron concentration in grain and relative canola yield.

The parameters of modified LS and MB models for relative grain yield in response to salinity and B concentrations are presented in Table 3.

Table 3. Best fit parameters for modified LS and MB models.

Parameter	Value	Unit
	Modified LS model	
Salinity threshold (EC_{cr})	3	dS m^{-1}
Responsiveness to salinity above EC_{cr} (b)	0.058	Y_r decrease per dS m^{-1}
Responsiveness to B (n)	0.0185	Y_r decrease per mg B kg^{-1}
B threshold (B_{cr})	10	mg kg $soil^{-1}$
	Modified MB model	
C_B	0.04714	kg mg^{-1}
C_{EC}	0.13035	m dS^{-1}
B_{max}	60.18	mg kg^{-1}
EC_{max}	20.83	dS m^{-1}

The parameters of each modified model for salinity and B were then fitted, however, only one factor alone predominates yield, using least square method. This way, the parameters were fitted to B data for the lowest salinity levels. For EC, the experimental data obtained from control treatments (0 mg B kg^{-1}) were used. These parameters were then substituted into modified LS and MB models, to obtain the plant response to simultaneous salinity levels and B concentrations.

Table 4. The calculated statistics ME, RSME, EF, CD, CRM and R^2 for the modified LS and MB models under variable salinity levels.

Model	RMSE	CD	EF	ME	CRM	R^2
LS	6.88	0.67	0.83	0.09	0.00	0.90
MB	8.10	2.42	0.76	0.07	0.00	0.84

The calculated statistics ME, RSME, EF, CD, CRM and R^2 for the models under variable salinity levels are presented in Table 4. As can be followed from Table 4, the coefficient of determination (R^2) for modified LS model is better than MB model. The RMSE values indicate that how much these models over/under estimate the results. By comparing the RMSE values, it seems that the modified LS model provides better estimation for relative dry matter than modified MB model. Comparison of the EF statistics indicates that the efficiency of modified LS model is higher than that of the modified MB model. The calculated maximum error (ME) statistics for LS model is higher than that of the modified MB model. The value of CD for LS model is lower than that of the MB model. Considering all statistics given in Table 4, one can reach the conclusion that the modified LS model provides more reasonable estimation of yield at various salinity levels than the MB model.

The average predicted relative yield as function of salinity for the modified LS and MB models against the experimental data are shown in Figs. 6 and 7, respectively.

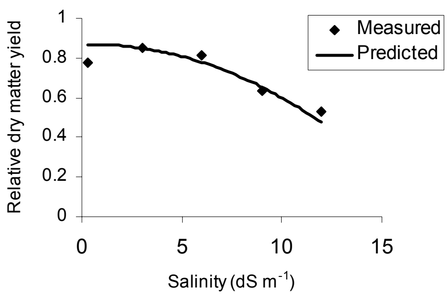

Figure 6. Comparison of measured and predicted relative yield according to modified LS model.

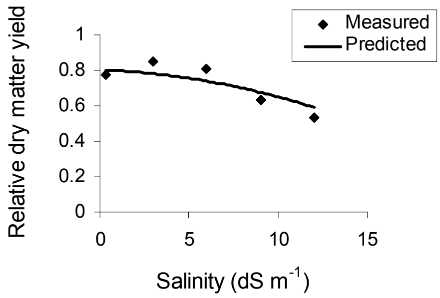

Figure 7. Comparison of measured and predicted relative yield according to modified MB model.

Comparison of the average predicted relative yield obtained with the modified LS and MB models and the measured values as a function of variable B levels is presented in Figs. 8 and 9, respectively. The corresponding calculated statistics ME, RSME, EF, CD, CRM and R^2 for the modified LS and MB models are presented in Table 5.

Table 5. The calculated statistics ME, RSME, EF, CD, CRM and R^2 for the modified LS and MB models under variable B concentrations.

Model	RMSE	CD	EF	ME	CRM	R^2
LS	1.69	1.30	0.98	0.02	0.00	1.00
MB	5.07	2.48	0.83	0.05	0.00	0.95

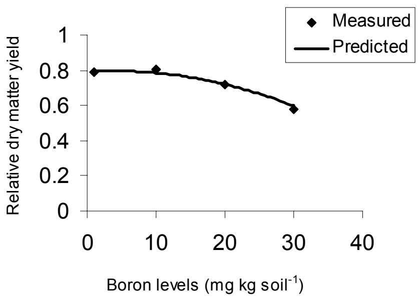

Figure 8. Comparison of measured and predicted relative yield according to modified LS model.

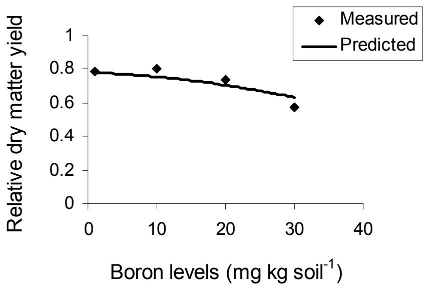

Figure 9. Comparison of measured and predicted relative yield according to modified MB model.

Comparison of the RMSE values for modified LS and MB models indicates that the LS model provide a better estimation for the relative dry matter yield in response to B levels than the modified MB model. The model efficiency statistics (EF) for the modified LS model (0.98) is much better than that of the modified MB model (0.83). The maximum error statistics (ME) for the modified LS model was less than that of the modified MB model. The coefficient of determination (CD) for the modified LS model is lower than that of modified MB model. Consequently, based on the calculated statistics, the modified LS model provided more accurate estimation for the average relative grain yield than the modified MB model.

The calculated statistics ME, RSME, EF, CD, CRM and R^2 for the models under variable salinity and B levels are presented in Table 6.

Table 6. The calculated statistics ME, RSME, EF, CD, CRM and R^2 for the modified LS and MB models under combined variable salinity and B concentrations.

Model	RMSE	CD	EF	ME	CRM	R^2
LS	16.11	0.95	0.56	0. 26	0.00	0.62
MB	15.80	3.34	0.57	0.23	0.00	0.64

As can be followed from Table 6, the coefficient of determination (R^2) for both models is the same. By comparing the RMSE values, it seems that the modified MB model provides a little better estimation for relative yield than modified LS model. By comparing the EF statistics indicate that this is the same for both models. The calculated maximum error (ME) statistics for LS model is higher than that of the modified MB model. The value of CD for LS model is lower than that of the MB model. Considering all statistics given in Table 6, It s concluded that both modified models provide reasonable estimation of yield at various salinity levels than the MB model.

The measured and estimated relative dry matter yields with the modified LS and MB models for all the experimental data are given in Figs. 10 and 11, respectively.

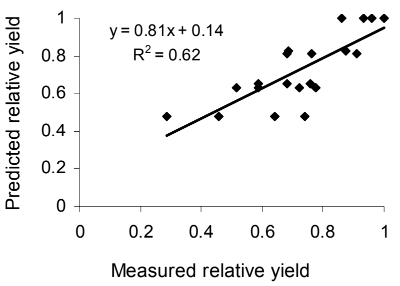

Figure 10. Comparison of measured and estimated relative dry matter yields according to modified LS model.

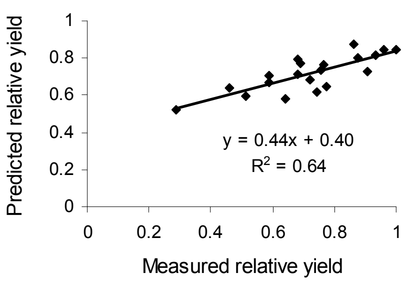

Figure 11. Comparison of measured and estimated relative dry matter yields according to modified MB model.

The maximum error (ME), RMSE, CD, EF, CRM and R^2 statistics as function of salinity for all B levels are presented in Table 7. Comparison of RMSE statistics for the modified LS and MB models at B_1 and B_4 levels indicates that value of RMSE statistics for the modified LS model is less than that of the modified MB model. This statistics at B_2 and B_3 levels for LS model is higher than that of MB model. This shows that the estimated relative yield at B_1 and B_4 levels by the modified LS model is closer than the modified MB model to the measured relative yield. Furthermore, at B_2 and B_3 levels MB model estimates relative yield better than LS model. Both models at B_4 level, have overestimated relative yield, while, other those predicted these models (at B_2 level) have underestimated relative yield. The modified LS model is better than modified MB model for B_1 and B_4 levels based on EF. In general, comparison of the calculated ME for modified LS and MB models indicates that at B_1, B_3 and B_4 levels, modified LS model is more suitable than modified MB model. By comparing the coefficient of determination (R^2) for both models indicates that LS model is better than MB model. Considering all statistics given in Table 7, one can reach the conclusion that the modified LS model provides more reasonable estimation of relative yield for various salinities at B_1 and B_4 levels than the MB model. Estimating relative yield at B2 and B3 levels, by MB model is more suitable than modified LS model.

Table 7. Statistics parameter for modified LS and MB models (relative grain yield as function of salinity for all B levels separately.

model	B Levels	ME	RSME	CD	EF	CRM	R^2
LS	B_1	0.14	10.25	0.81	0.80	0.01	0.84
MB	B_1	0.18	14.17	4.75	0.63	0.00	0.84
LS	B_2	0.26	17.27	0.35	-0.32	0.01	0.56
MB	B_2	0.12	12.47	1.67	0.31	0.06	0.47
LS	B_3	0.17	15.44	0.69	0.02	0.00	0.37
MB	B_3	0.18	14.77	2.16	0.10	0.01	0.18
LS	B_4	0.19	21.96	7.04	0.46	-0.04	0.71
MB	B_4	0.23	23.40	3.96	0.38	-0.09	0.66

The measured and estimated relative grain yields based on the modified LS and MB models as a function of salinity at different B levels are presented in Figs. 13 and 14.

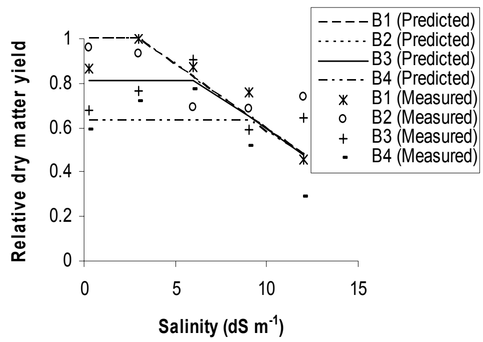

Figure 12. Canola relative grain yield as function of salinity under variable B levels based on the modified LS model

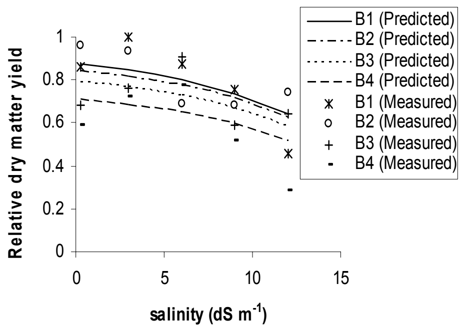

Figure 13. Canola relative grain yield as function of salinity under variable B levels based on the modified MB model

For the LS model (Figure 12), the outer line depicts yield due to dominant salinity, and the inner lines (horizontal) set the yield when B is the dominant stress. At low salinity, the main effect is related to B concentration and at high salinity the main effect is attributed to salinity. Agreement between measured and calculated yields for the studied B and salinity range is good. The threshold value of salinity, EC_{cr}, specific to each B level, where salinity becomes the dominant stress and maximum yield for each salinity level are shown in Figure 12. When the salinity value was greater than EC_{cr}, no effect of B concentration on yield was apparent. The threshold value of salinity increased with higher B concentration and the maximum grain yields decreased with increasing B concentration and were different from one another (Figure 12). Ben-Gal and Shani (2002) reported similar results. Figure 13 explains the combined effect of salinity and B on relative dry matter yield. The MB model overestimates the relative yield when the two stresses are applied (at B_4 levels).

Conclusions

Excess B was found to decrease yield of canola. This effect was inhibited when plants were exposed to simultaneous B and salinity stresses. Both irrigation water salinity and B concentration influenced WUE of the plants; this effect, in case of B levels was in the same manner as it influenced yield. In general, the LS model (dominant-stress-factor) explains the interactive effect of B and salinity on yield of canola plant better than the MB model. Therefore, the use of modified LS model for estimating canola relative dry matter yield in salinity and B stresses is recommended. The threshold value of salinity increased with higher B concentration and the maximum dry matter yields decreased with increasing B concentration. The results of this study have significance in management of high salinity and high B conditions.

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