Research Article

Sunflower (*Helianthus annuus* L.) Growth, Yield and Oil Quality Response to Combined Application of Nitrogen and Boron

Azhar Mehmood[1,2,*], Muhammad Farrukh Saleem[2], Muhammad Tahir[2], Muhammad Aqeel Sarwar[3], Tasawer Abbas[4], Ali Zohaib[2], Hafiz Tassawar Abbas[5]

[1]University College of Agriculture and Environmental Science, The Islamia University of Bahawalpur, Pakistan; [2]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan; [3]Crop Sciences Institute, National Agricultural Research Centre Islamabad, Pakistan; [4] College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan; [5]Department of Plant pathology, Lasbela University of Agriculture Water and Marine Sciences Uthal, District Lasbela, Balochistan, Pakistan.

Abstract | Imbalance use of nutrients is one of the main reasons of low yield of the sunflower. The use of essential macro and micronutrients in the right proportion and optimum quantity is the key factor to boost and sustain the crop productivity. Among plant nutrient deficiencies, nitrogen and boron limitation is the most prevailing problem in the world, which is involved in the decline of sunflower production. Therefore, a field experiment was conducted to examine the combined effect of nitrogen and boron on growth, yield and oil quality of sunflower hybrids during 2009. Two nitrogen levels (0 and 150 kg ha^{-1}) and three boron levels (0, 2 and 3 kg ha^{-1}) were tested against two sunflower hybrids (Hysun-33 and DK-4040). All the growth and yield components like plant height, stem diameter, head diameter, achene and biological yield were significantly affected by varying levels of nitrogen and boron fertilizers. Results revealed that boron/nitrogen synergetic effect additively increased yield and yield components in sunflower plant. The oil and protein contents of sunflower were significantly affected by varying levels of both nitrogen and boron and maximum oil contents were observed when boron was applied @ 2 kg ha^{-1} with 0 kg ha^{-1} of nitrogen whereas maximum protein contents were recorded when 2 kg ha^{-1} boron was applied in combination with 150 kg ha^{-1} of nitrogen of both hybrids (H_1=Hysun-33 and H_2=DK-4040). The combined application of nitrogen (N_1) (150 kg ha^{-1}) and boron B_1 (2 kg ha^{-1}) also resulted in maximum net income (88518 Rs.) and benefit cost ratio (1.25) for Hysun-33.

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***Correspondence** | Azhar Mehmood, The Islamia University of Bahawalpur, Pakistan; **Email:** azharagronomist@gmail.com
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Introduction

The major oilseed crops of Pakistan include cotton, rapeseed, mustard, sunflower and canola etc. During 2015-16, 3.264 million tonnes edible oil/oilseeds of value Rs. 284.546 (US$ 2.710 billion) had been imported. Total availability of edible oils from all sources was 3.726 million tonnes during 2015-16 (Govt. of Pakistan, 2016). Amongst oilseeds sunflower can never be neglected, as it is adapted to environmental conditions of Pakistan and rich in nutrition. In Pakistan sunflower was cultivated on an area of 384 thousand acres with total production of oilseed 190 thousand tonnes and oil production 76 tonnes (Govt. of Pakistan, 2014). To increase yield and quality in sunflower cultivation, nitrogen fertilizer is used insensitively, because nitrogen (N) is an essential mineral nutrient for plant growth and development.

Links Researchers

Nitrogen enhances vegetative growth and rate of photosynthesis, imparts green colour to the plants and is also a part of chlorophyll (Brady and Well, 2005). Nitrogen deficiency induces modification of many morphological and physiological parameters: limitation of growth, leaf number and leaf area has been reported. Therefore, due to the large nitrogen requirement of the crops, one of the aims of agricultural researchers is to choose best N fertilization management (type, dose and time of application), so as to maintain high yield, to decrease potential groundwater pollution and to increase soil fertility. Boron is a micronutrient required for all plant nutrition. The main functions of boron relate to cell wall strength and development, cell division, fruit and seed development, sugar transport, and hormone development. Some functions of boron interrelate with those of nitrogen, phosphorus, potassium and calcium in plants. Balanced nutrition is essential for optimum crop growth. Boron (B) is considered as an essential element for plant growth and development. Reproductive growth in plant is more sensitive to low B, than vegetative growth (Ahmad et al., 2009). Boron is considered to be essential for actively growing regions of plants, such as root tips, new leaf and bud development (Rerkasem, 1996), also involved in metabolic pathways and can act in regulation of metabolic activities. Its deficiency affects the yield of fruits, vegetables, nuts, and grains as well as the quality of harvested crops. Increased boron may promote root elongation in acidic, high-aluminum soils (Loomis and Durst, 1992). The present study was therefore planned to optimize the dose of nitrogen and boron and evaluate their interactive effect on growth, yield and quality of sunflower hybrids.

Materials and Methods

The experiment was conducted at Agronomic Research Area, University of Agriculture Faisalabad, Pakistan (31° N latitude, 73° E longitude, and 184.4 m altitude) during 2009. Soil of the experimental area was quite uniform, so a composite and representative soil sample to a depth of 30 cm was obtained with soil auger, prior to sowing of the crop. Soil was analyzed for its various physio-chemical properties by using the methods as described by Homer and Pratt, 1961 (Table 1).

The experiment was laid out in randomized complete block design under factorial arrangements with three replications having a net plot size of 3 m × 5 m. The experiment was comprised of three factors i.e., Factor (A) = Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Factor (B) = Nitrogen levels (N) N_0 = 0 kg ha^{-1} (control), N_1 = 150 kg ha^{-1} Factor (C) = Boron levels (B) = Bo = 0 kg ha^{-1} (control), B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}. The seedbed was prepared by cultivating the field for 2-3 times with tractor-mounted cultivator each followed by planking. Sunflower hybrids were sown on ridges with the help of dibbler keeping R × R and P × P distances of 75 cm and 25 cm, respectively. Seed rate of 5 kg ha^{-1} was used. Nitrogen and boron were applied as per treatment and phosphorus was applied @ 100 kg ha^{-1}. Half of the nitrogen and full phosphorus was applied at the time of sowing and remaining half nitrogen was applied with first irrigation. Boron was applied at sowing and with first irrigation using available resources of boric acid (17% Boron). All other agronomic practices, except treatments under study, were kept normal and uniform for all the treatments. Plant protection measures were adopted to keep crop free of weeds, insect pests and diseases. The crop was harvested on October 31, 2009.

Table 1: *Physical and chemical characteristics of experimental soil*

Determination		Unit	Value
A	Physical Analysis		
	Sand	%	65
	Silt	%	16
	Clay	%	19
	Textural Class	Sandy Clay Loam	
B	Chemical Analysis		
	Saturation	%	36.5
	pH	----	7.80
	EC	d S m^{-1}	1.30
	Organic Matter	%	0.79
	Total Nitrogen	%	0.047
	Available Phosphorous	ppm	8.75
	Available Potassium	ppm	165
	Boron	ppm	0.39

Procedure adopted for data collection

The height of ten randomly selected plant was measured (in cm) from each plot at full maturity. At final harvesting, stem diameter of ten randomly selected plants (at base, middle and top of each stem and the average value was taken) was determined with the help of vernier caliper. After threshing, diameter (in cm) of ten randomly selected heads was also measured with the help of vernier caliper and average diameter in cm was computed. Number of achenes in 10 randomly selected heads were counted from each treatment and then averaged per head. Five samples, each of 1000-achenes were randomly taken from the seed lot of each plot to calculate average weight of 1000-achenes. Economic/achene yield and biological yield were calculated per hectare using the yield of every plot with the help of electrical balance. Oil content was determined by Soxhlet Fat Extraction Method (AOAC, 1990). The collected data were analyzed statistically by using the Fisher's analysis of variance technique and treatments means were compared by using LSD test at 5% probability level (Steel et al., 1997).

Results and Discussion

Crop phenology

Both hybrids (H_1=Hysun-33 and H_2=DK-4040) significantly affected the time taken to 50% heading (Table 2). Hysun-33 took maximum number of days (73.16) for attaining 50% heading and DK-4040 took minimum (70.16) days. Nitrogen and boron also significantly affected the days taken to 50% heading (Table 2). Maximum value of time taken to 50% heading (74.66) was recorded where applied nitrogen level was 150 kg ha^{-1} and minimum days (68.66) were taken in control treatment. Similarly maximum days to 50% heading (73) were obtained with boron level B_2 (3 kg ha^{-1}) and minimum (70.50) in control treatment (B_0). Data showed significant highest order interaction among hybrid, nitrogen and boron (H×N×B). The maximum value (78) for days taken to 50% heading was depicted when the level of boron and nitrogen application to DK-4040 was 3 kg ha^{-1} and 150 kg ha^{-1}, respectively and minimum (65) when DK-4040 was grown without nitrogen and boron.

Significant difference among both hybrids (H_1=Hysun-33 and H_2=DK-4040) was observed for the days taken to 50% flowering (Table 2). Hybrid Hysun-33 took maximum number of days (61.33) and hybrid DK-4040 took minimum number of days (57.50) for completing 50% flowering. This parameter was also significantly affected with the application of nitrogen and boron individually. The nitrogen level N_1 (150 kg ha^{-1}) increased the time taken to 50% flowering (62.50) and control lowered (56.33) the value of the parameter. Boron level B_2 (3 kg ha^{-1}) also enhanced the time taken to 50% flowering (60.25) and it was at par with the value 59.50 at boron level B_1 (2 kg ha^{-1}) and control (B_0) reduced the value (58.50) of the time taken to 50% flowering. The maximum value of interaction (65.00) between hybrid, nitrogen and boron was obtained with the treatment combinations $H_1B_2N_1$ (Hysun-33, 3 kg ha^{-1} boron (B) and nitrogen (N) 150 kg ha^{-1}) and $H_1B_1N_1$ (Hysun-33, 2 kg ha^{-1} B and 150 kg ha^{-1} N) while minimum value (953) was recorded in $H_2B_0N_0$ (Hysun-33, 0 kg ha^{-1} B and 0 kg ha^{-1}) application.

Table 2: *Phenology of sunflower as affected by combined application of nitrogen and boron.*

Treatments	Days to 50% heading	Days to 50% flowering	Days to 50% maturity
Hybrids (H)			
H_1 (Hysun-33)	73.16 a	61.33 a	98.50 a
H_2 (DK-4040)	70.16 b	57.50 b	93.00 b
LSD (5%)	0.650	0.162	0.162
Nitrogen levels (N)			
N_0 (kg ha^{-1})	68.66 b	56.33 b	93.33 b
N_1 (kg ha^{-1})	74.66 a	62.50 a	98.16 a
LSD (5%)	0.650	0.699	0.711
Boron levels (B)			
B_0 (kg ha^{-1})	70.50 c	58.50 b	95.75
B_1 (kg ha^{-1})	71.50 b	59.50 a	95.75
B_2 (kg ha^{-1})	73.00 a	60.25 a	95.75
LSD (5%)	0.650	0.856	NS
H x B x N			
H_1 x B_0 x N_0	71.00 d	59.00 d	95.00 c
H_1 x B_0 x N_1	75.00 b	62.00 b	102.0 a
H_1 x B_1 x N_0	71.00 d	57.00 e	95.00 c
H_1 x B_1 x N_1	75.00 b	65.00 a	103.0 a
H_1 x B_2 x N_0	71.00 d	60.00 cd	96.00 c
H_1 x B_2 x N_1	76.00 b	65.00 a	100.0 b
H_2 x B_0 x N_0	65.00 f	53.00 g	91.00 e
H_2 x B_0 x N_1	71.00 d	60.00 cd	95.00 c
H_2 x B_1 x N_0	67.00 e	55.00 f	92.00 de
H_2 x B_1 x N_1	73.00 c	61.00 bc	93.00 d
H_2 x B_2 x N_0	67.00 e	54.00 fg	91.00 e
H_2 x B_2 x N_1	78.00 a	62.00 b	96.00
LSD (5%)	1.594	1.71	1.743

Means not sharing the same letters differ significantly at 5 % probability.
Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Nitrogen levels (N) N_0 = 0 kg ha^{-1}, N_1 = 150 kg ha^{-1} Boron levels (B) = Bo = 0 kg ha^{-1}, B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}. NS= Non significant

Both the hybrids (H_1 and H_2) significantly differed for days taken to 50% maturity (Table 2). Hybrid Hysun-33 took more number of days (98.50) and hybrid DK-4040 took less number of days (93) for completing 50% maturity. Days taken to 50% maturity were increased (98.16) with the application of nitrogen level (150 kg ha^{-1}) whereas control (N_0) lowered the value (93.33) of the parameter (table 2). Boron individually did not affect the time taken to 50% maturity. Regarding interaction between hybrid (H), nitrogen (N), and boron (B) (Table 2), the more number of days to 50% maturity (103) were taken with the treatments $H_1B_1N_1$ (Hybrid Hysun-33, 2 kg ha^{-1} B, 150 kg ha^{-1} N) and minimum (91) days by $H_2B_0N_0$ (Hybrid DK-4040, 0 kg ha^{-1} B, 0 kg ha^{-1} N) and $H_2B_2N_0$ (Hybrid DK-4040, 3 kg ha^{-1} B, 0 kg ha^{-1} N). The treatments $H_2B_2N_0$, $H_2B_0N_0$ were statistically similar.

Increase in number of days to different growth stages could be due to increased vegetative growth. Increased time to sunflower growth stages was also responsive to boron due to its involvement in cell wall synthesis and structure, protein, nucleic acid and carbohydrate metabolism, sugar transport and membrane functions and integrity. A facilitative response of nitrogen to extend the plant growth stages was due to its involvement in structural support of cell membrane as well as in non-structural components of enzymes, nucleic acids, amino acids and chlorophyll pigments (Mojiri and Arzani, 2003; Cechin and Fumis, 2004; Sadras, 2006; Seilsepour and Rashidi, 2011).

Yield and yield related traits

Table 3 shows significant difference for plant height of sunflower between both hybrids (H_1=Hysun-33 and H_2=DK-4040). Maximum plant height (151 cm) was obtained by Hysun-33 and DK-4040 attained 136 cm plant height. Plant height at maturity was significantly increased with the increasing levels of both boron and nitrogen fertilizers. Nitrogen level N_1 (150 kg ha^{-1}) increased the plant height of sunflower (155 cm) and N_0 level decreased (132 cm) the plant height. The boron level B_1 (2 kg ha^{-1}) increased the plant height (148 cm) whereas the boron level B_0 (control) gave minimum value (139 cm) of plant height at maturity. For hybrid and boron interaction, H_1B_1 (Hysun-33 and 2 kg ha^{-1} B) gave maximum plant height (158 cm) and minimum (133 cm) was produced by H_2B_0 (DK-4040 and 0 kg ha^{-1} boron) that was at par with H_2B_2 (DK-4040 and 3 kg ha^{-1} boron). Regarding hybrid × nitrogen interaction (H×N) maximum height (164.0 cm) was achieved in H_1N_1 treatment (Hysun-33 and nitrogen level 150 kg ha^{-1}) and minimum (125 cm) was observed in H_2N_0 treatment (DK-4040 and nitrogen level 0 kg ha^{-1}).

Both the hybrids (H_1=Hysun-33 and H_2=DK-4040) significantly affected the head diameter of sunflower (Table 3). Maximum head diameter (18.18 cm) was produced by DK-4040 and Hysun-33 produced minimum head diameter with (17.18 cm). Nitrogen and boron also significantly affected head diameter of sunflower. Nitrogen level N_1 (150 kg ha^{-1}) gave maximum head diameter (20.17 cm) and minimum value (15.19 cm) was recorded in control (N_0). Boron level B_1 (2 kg ha^{-1}) increased head diameter (18.72 cm) and B_0 (0 kg B ha^{-1}) gave 16.84 cm head diameter. The interactions of hybrid and boron (H×B), hybrid and nitrogen (H×N), boron and nitrogen (B×N), hybrid, nitrogen and boron (H×N×B) were found to be significant. Maximum head diameter (19.25 cm) was given by H_2B_1 treatment (DK-4040 and 2 kg ha^{-1} B) as compared to control H_1B_0 (Hysun-33 and 0 kg ha^{-1}B) where it was 16.27 cm. For hybrid × nitrogen interaction (H×N) the treatment H_2N_1 (hybrid DK-4040 and 150 kg ha^{-1} N) produced head of maximum diameter (20.61 cm) and H_1N_0 (hybrid Hysun-33 and 0 kg ha^{-1} N) produced head of minimum diameter (14.63 cm). Regarding boron and nitrogen interaction (B×N) the treatment B_1N_1 (Boron 2 kg ha^{-1} and nitrogen 150 kg ha^{-1}) was found best, which produced head of 21.26 cm and minimum head, was observed in the treatment B_0N_0 (0 kg B with 0 kg N ha^{-1}). For hybrid, boron and nitrogen interaction (H×B×N) maximum head diameter (21.78 cm) was obtained when DK-4040 was grown with 2 kg boron and 150 kg N ha^{-1}and minimum head of 13.90 cm was found in Hysun-33 when it was supplied with 0 kg B and 0 kg N ha^{-1}.

Both the hybrids (Hysun-33 and DK-4040) differed significantly for No. of achenes per head of sunflower (Table 3). Maximum number of achenes per head (732.2) was obtained from Hysun-33 and DK-4040 gave 639.2. Nitrogen and boron significantly affected No. of achenes per head of sunflower. Maximum value of number of achenes per head (719.2) was recorded with the application of N_1 (150 kg ha^{-1}) and lower value (652.3) was recorded in control treatment N_0 (0 kg ha^{-1} N). B_1 level of boron (2 kg ha^{-1}) gave maximum value (703.2) and control gave 667.0 value. In case of interactions, interaction of H×N, and B×N were found to be significant. Maximum value of interaction between hybrid and nitrogen was 716.89

where treatment combination was $H_1 \times N_0$ and minimum value was given by $H_2 \times N_0$. For boron and nitrogen interaction, $B_0 \times N_1$ gave maximum value (740.16) and minimum value (637.83) was given by treatment combination $B_0 \times N_0$.

Table 3: *Plant height, head diameter, head diameter, No. of achenes per head, and 1000 achenes weight of sunflower as affected combined application of nitrogen and boron.*

Treatments	Plant height (cm)	Head diameter (cm)	No. of achenes per head	1000 achenes weight (g)
Hybrids (H)				
H_1 (Hysun-33)	151 a	17.18 b	732.2 a	47.21
H_2 (DK-4040)	136 b	18.18 a	639.2 b	47.24
LSD (5%)	1.53	0.017	6.047	NS
Nitrogen levels (N)				
N_0 (kg ha^{-1})	132 b	15.19 b	652.3 b	42.75 b
N_1 (kg ha^{-1})	155 a	20.17 a	719.2 a	51.70 a
LSD (5%)	1.53	0.017	6.047	0.170
Boron levels (B)				
B_0 (kg ha^{-1})	139 c	16.84 c	667.0 c	44.35 c
B_1 (kg ha^{-1})	148 a	18.72 a	703.2 a	49.24 a
B_2 (kg ha^{-1})	143 b	17.49 b	687.0 b	48.08 b
LSD (5%)	1.883	0.021	7.406	0.209
H x B				
H_1 x B_0	146 c	16.27 f	733.00	44.58 c
H_1 x B_1	158 a	18.19 b	722.50	49.12 a
H_1 x B_2	151 b	17.08 e	741.33	47.94 b
H_2 x B_0	133 e	17.40 d	645.00	44.12 d
H_2 x B_1	139 d	19.25 a	626.50	49.37 a
H_2 x B_2	135 e	17.90 c	646.33	48.22 b
LSD (5%)	2.663	0.030	NS	0.301
H x N				
H_1 x N_0	139 c	14.63 d	716.89 b	42.65
H_1 x N_1	164 a	19.74 b	747.67 a	51.77
H_2 x N_0	125 d	15.75 c	616.67 d	42.84
H_2 x N_1	146 b	20.61 a	661.89 c	51.63
LSD (5%)	2.174	0.025	8.689	NS
B x N				
B_0 x N_0	128	14.43 f	637.83 f	39.91 f
B_0 x N_1	151	19.25 c	740.16 a	53.67 a
B_1 x N_0	137	16.18 d	696.17 c	48.74 c
B_1 x N_1	160	21.26 a	652.83 e	43.52 e
B_2 x N_0	132	14.96 e	666.33 d	44.82 d
B_2 x N_1	154	20.02 b	721.33 b	52.65 b
LSD (5%)	NS	0.030	10.642	0.301
H x B x N				
H_1 x B_0 x N_0	134	13.90 k	685.67	40.30 h
H_1 x B_0 x N_1	158	18.65 e	750.00	48.86 c
H_1 x B_1 x N_0	146	15.65 g	715.00	44.42 e
H_1 x B_1 x N_1	170	20.73 b	780.33	53.81 a
H_1 x B_2 x N_0	139	14.34 j	695.00	43.24 g
H_1 x B_2 x N_1	164	19.82 d	767.67	52.64 b
H_2 x B_0 x N_0	123	14.96 i	590.00	39.52 i
H_2 x B_0 x N_1	144	19.85 d	642.33	48.72 c
H_2 x B_1 x N_0	128	16.72 f	617.67	45.21 d
H_2 x B_1 x N_1	150	21.78 a	700.00	53.52 a
H_2 x B_2 x N_0	126	15.58 h	610.67	43.80 f
H_2 x B_2 x N_1	145	20.22 c	675.00	52.65 b
LSD	NS	0.043	NS	0.418

Means not sharing the same letters differ significantly at 5 % probability.
Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Nitrogen levels (N) N_0 = 0 kg ha^{-1}, N_1 = 150 kg ha^{-1} Boron levels (B) = Bo = 0 kg ha^{-1}, B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}. NS= Non significant

Table 3 shows that hybrids (H_1= Hysun-33 and H_2=DK-4040) did not differ significantly for thousand achene weight of sunflower (table 3). Nitrogen level N_1 (150 kg ha^{-1} N) gave maximum value (51.70 g) and control N_0 gave 42.75 g (table 3). Maximum value of thousand achene weight (49.24 g) was recorded with boron level B_1 (2 kg ha^{-1}) and minimum value (44.35 g) was recorded in control. Significant differences were observed among hybrid × boron interaction, boron × nitrogen and highest order interaction (H×B×N) for thousand achene weight of sunflower. Among interaction treatments H_2B_1 produced maximum thousand achene weight (49.37 g) and the treatment H_2B_0 (DK-4040 and 0 kg ha^{-1} B) produced minimum thousand achene weight (44.12 g). For B×N interaction maximum value (53.67 g) was given by B_0N_1 treatment combination and minimum (39.91 g) was obtained by $B_0 \times N_0$ treatment combination. In case of three factors interaction (H × B × N) maximum thousand achene weight (53.81 g) was produced by, however it was at par with $H_2B_1N_1$ and minimum (39.52 g) thousand achene weight was observed in DK-4040 when it was supplied with 0 kg N and 0 kg B ha^{-1}.

Stem diameter of sunflower was significantly affected for both hybrids (Table 3). Maximum stem diameter (2.08 cm) of sunflower was produced by Hysun-33 and DK-4040 produced 2.05 cm stem diameter. Highest value of stem diameter (2.17 cm) was obtained with the application of nitrogen level N_1 (150 kg ha^{-1}) and lowest value (1.96 cm) was recorded in control (Table 4). Boron level B_1 (2 kg ha^{-1}) produced maximum value (2.08 cm) of stem diameter and control produced lowest value (2.05 cm). The maximum stem diameter (2.19 cm) was obtained when nitrogen 150 kg ha^{-1} was applied on Hysun-33 whereas minimum (1.95 cm) was attained where DK-4040 was treated with 0 kg N ha^{-1}.

Data in Table 4 showed that economic/achene yield of sunflower was affected by both the hybrids (H_1=Hysun-33 and H_2=DK-4040). Maximum achene yield (3485 kg ha^{-1}) was obtained from Hysun-33 while DK-4040 gave 3267 kg ha^{-1} achene yield. Maximum (3748 kg ha^{-1}) where nitrogen level was 150 kg ha^{-1} and minimum (3004 kg ha^{-1}) where control treatment was applied (table 4). Boron level B_1 (2 kg ha^{-1}) gave maximum value of achene yield (3462 kg ha^{-1}) and control produced minimum achene yield (3266 kg ha^{-1}). Moreover, boron × nitrogen interaction was found to be significant. For boron nitrogen interaction, maximum yield (3870 kg ha^{-1}) was given by the treatment B_1N_1 (2 kg ha^{-1} B and 150 kg ha^{-1} N) and minimum (2949 kg ha^{-1}) was obtained by B_0N_0 (0 kg ha^{-1} B and 0 kg ha^{-1} N).

Table 4: *Stem diameter, economic/achene yield, biological yield and harvest index as affected by combined application of nitrogen and boron.*

Treatments	Stem diameter (cm)	Economic/ achene Yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Hybrids (H)				
H_1 (Hysun-33)	2.08 a	3485 a	14504 a	24.02
H_2 (DK-4040)	2.05 b	3267 b	13715 b	23.82
LSD (5%)	0.01	20.7	184.5	NS
Nitrogen levels (N)				
N_0 (kg ha^{-1})	1.96 b	3004 b	12708 b	23.67 b
N_1 (kg ha^{-1})	2.17 a	3748 a	15511 a	24.16 a
LSD (5%)	0.01	20.7	184.56	0.33
Boron levels (B)				
B_0 (kg ha^{-1})	2.05 c	3266 c	13446 c	24.35 a
B_1 (kg ha^{-1})	2.08 a	3462 a	14691 a	23.48 c
B_2 (kg ha^{-1})	2.06 b	3400 b	14191 b	23.93 b
LSD (5%)	0.01	25.3	226.0	0.406
H x B				
H_1 x B_0	2.06	3370	13894	24.30
H_1 x B_1	2.11	3578	15069	23.68
H_1 x B_2	2.07	3507	14548	24.07
H_2 x B_0	2.03	3161	12998	24.39
H_2 x B_1	2.06	3346	14314	23.29
H_2 x B_2	2.06	3294	13833	23.78
LSD (5%)	NS	NS	NS	NS
H x N				
H_1 x N_0	1.96 c	3117	13095	23.83
H_1 x N_1	2.19 a	3853	15913	24.20
H_2 x N_0	1.95 c	2890	12321	23.51
H_2 x N_1	2.15 b	3644	15108	24.13
LSD (5%)	0.020	NS	NS	NS
B x N				
B_0 x N_0	1.94	2949 f	11779 e	24.99 a
B_0 x N_1	2.15	3583 c	15113 b	23.70 c
B_1 x N_0	1.97	3054 d	13536 c	22.55 d
B_1 x N_1	2.20	3870 a	15846 a	24.41 b
B_2 x N_0	1.97	3008 e	12809 d	23.47 c
B_2 x N_1	2.16	3793 b	15572 a	24.38 b
LSD (5%)	NS	35.8	319.67	0.57
H x B x N				
H_1 x B_0 x N_0	1.95	3050	12236	24.89
H_1 x B_0 x N_1	2.17	3691	15552	23.72
H_1 x B_1 x N_0	1.98	3180	13934	22.82
H_1 x B_1 x N_1	2.23	3976	16204	24.54
H_1 x B_2 x N_0	1.97	3122	13115	23.80
H_1 x B_2 x N_1	2.18	3892	15982	24.35
H_2 x B_0 x N_0	1.94	2848	11321	25.10
H_2 x B_0 x N_1	2.13	3475	14674	23.67
H_2 x B_1 x N_0	1.96	2929	13139	22.29
H_2 x B_1 x N_1	2.17	3764	15489	24.29
H_2 x B_2 x N_0	1.97	2894	12504	23.14
H_2 x B_2 x N_1	2.15	3694	15162	24.42
LSD	NS	NS	NS	NS

Means not sharing the same letters differ significantly at 5 % probability.
Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Nitrogen levels (N) N_0 = 0 kg ha^{-1}, N_1 = 150 kg ha^{-1} Boron levels (B) = Bo = 0 kg ha^{-1}, B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}. NS=Non significant

Table 4 showed that both the hybrids (H_1=Hysun-33 and H_2=DK-4040) affected the biological yield of sunflower. Maximum biological yield (14504 kg ha^{-1}) was produced by Hysun-33 while DK-4040 produced minimum (13715 kg ha^{-1}). Biological yield of sunflower was significantly affected by the application of various levels of both nitrogen and boron. Maximum value of biological yield (15511 kg ha^{-1}) was found with the application of nitrogen level N_1 (150 kg ha^{-1}) and minimum (12708 kg ha^{-1}) was recorded in control. Biological yield was maximum (14691 kg ha^{-1}) where boron level was 2 kg ha^{-1} and minimum was (13446 kg ha^{-1}). Significant difference in biological yield of sunflower was found in case of among boron × nitrogen interaction (Table 4) for biological yield of sunflower. In case of interaction between boron and nitrogen (B×N) the treatment B_1N_1 was found best which produced 15846 kg ha^{-1} biological yield while minimum biological yield (11779 kg ha^{-1}) was produced by the treatment B_0N_0 (0 kg ha^{-1} B and 0 kg ha^{-1} N).

Table 4 shows harvest index was not significantly by both the hybrids (H_1 and H_2). It was evident from the table that harvest index of sunflower was maximum (24.16) where nitrogen (150 kg ha^{-1}) was applied and was minimum (23.67) in control (0 kg ha^{-1}). Different boron levels also affected the harvest index of sunflower and maximum value of harvest index (24.35) of sunflower was obtained with application of 2 kg B ha^{-1} and minimum value was recorded in control (23.48). Boron × nitrogen (B×N) interaction was found to be significant for harvest indices of sunflower. Maximum value (24.99 %) of harvest index was given by B_0N_0 (0 kg ha^{-1} B and 0 kg ha^{-1} N) and minimum (22.55 %) was obtained by B_1N_0 treatment (2 kg ha^{-1} B and 0 kg ha^{-1} N).

Shaaban et al. (2004) reported that both boron and nitrogen were found to interact positively to improve growth parameters suggesting better assimilation of enhanced nitrogen in the presence of sufficient boron contents. Sharma et al. (1999) reported that application of boron significantly increased plant height. The earlier researchers working on sunflower such as Unger, 1983 and Iqbal, 1993 found that increase in plant height with increasing N rates was due to better nutrient management.

Boron is actually involved in enhancing the translocation of photoassimilates from vegetative to reproductive parts as it plays an important role in translocation of sugars, which are reported having incremental effect on metabolic activities (Reddy et al., 2003). These results are in line with result of Oyinlola (2007) who found that the head diameter of sunflower increases with increasing boron level. Bakhsh et al. (1999) reported increase in head diameter with increase in N fertilizer application.

With increase in head diameter, the number of florets per head also increased. More number of achenes per head with the combined application of nitrogen and boron could be due to its important role in pollen tube formation by cross linking and muco-de-esterification of cell wall pectins (Renukadevi et al., 2002). Consequently more number of florets led to more number of seeds. These results are in line with those reported by Sadiq et al. (2000) who observed increase in number of achenes per head with increase in N.

The efficient translocation of photosynthates due to adequate nitrogen nutrition favoured better seed filling thus increasing the number of filled seeds per head and also the seed weight per head (Nandagopal et al., 1995). These results are supported by findings of Ceyhan et al. (2008) who reported that 1000-achene weight was significantly different among sunflower genotypes. Sadiq et al. (2000) reported increase in 1000-achene weight with increasing nitrogen application.

Improved growth of stem can be attributed to the role of boron and nitrogen in chlorophyll and nucleic acid synthesis, cell differentiation, and elongation, turgidity and lignin biosynthesis (Hellal et al., 2009).

The increased achene yield with the application of nitrogen and Boron was due to its important role in pollen germination, flowering, proper seed setting, fruiting processes, sugar metabolism and balance between net photosynthetic rate and respiration (Khan et al., 2006). Nitrogen nutrition enhances sugar production which leads towards more export of sugars from leaves to the storage organs as in roots and seeds. This accumulation of sugars improves the yield of sunflower (Yu et al., 2002). These results are similar to those found by Oyinlola (2007) who reported that achene yield was increased with application of boron up to certain limit. Maragatham and Chellamuthu (2000), Reddy et al. (2002) and Sumathi and Rao (2007) reported increase in achene yield by N application.

The total biomass of the crop produced by utilizing the resources available at the time is known as biological yield. Plant height, No. of achenes per head and 1000-achene weight contribute towards biological yield of sunflower. The results of our study are in line with the findings of Gitte et al. (2005) who reported that increased biological yield could be due to the role of boron in cell elongation, cell division and biomass accumulation. These results are in agreement with those of Zahoor et al. (2011). They reported that application of boron increases the biological yield due to its possible positive correlation present between boron and other micronutrients and enzymatic activity. Hence stem diameter, head diameter and plant height increased and ultimately biological yield of sunflower was also increased. These results are supported by Gitte et al. (2005) who reported that an increase in biological yield might be due to role of boron in cell elongation, cell division and biomass accumulation.

Translocation of photoassimilates might be increased due to boron application which contributed to the achene yield by reducing biological mass due to translocation. Increased value of harvest index by the application of boron has also been described by Reddy et al. (2003). Iqbal (1993) reported decrease in harvest index with sequential increase in nitrogen to sunflower.

Leaf boron content

Leaf boron content of sunflower was significantly affected by Hysun-33 and DK-4040 (Table 5). Maximum leaf boron (41.76 ppm) was observed in DK-4040 while Hysun-33 absorbed 40.92 ppm B. Sunflower leaf absorbed more boron amount (41.75 ppm) with the application of nitrogen level N_1 (150 kg ha^{-1}) and absorbed less amount (40.93 ppm) in control treatment (Table 5). Maximum amount of boron (47.97 ppm) was found in leaf of sunflower where boron level was 3 kg ha^{-1} and minimum (35.59 ppm) with 0 kg B ha^{-1}. Boron content in leaf of sunflower varied significantly for their first order as well as highest order interactions. In case of hybrid × boron interaction Hysun-33 absorbed 47.98 ppm B when 3 kg B ha^{-1} was applied which was at par with the B absorbed (47.97 ppm) by DK-4040 at same B application level (3 kg ha^{-1}) and minimum was absorbed (34.87 ppm) when 0 kg B was applied to Hysun-33. For hybrid and nitrogen interaction (H×N) the treatment H_2N_1 gave significantly maximum value of leaf boron content (42.38 ppm). In case of boron and nitrogen interaction (B×N), the treatment B_2N_1 (3 kg ha^{-1} B and 150 kg ha^{-1} N) gave maximum B content in leaf (49.37 ppm) and B_0N_0 showed minimum value (35.40 ppm). For hybrid × boron × nitrogen interaction (H×B×N) maximum amount (50.03 ppm) of boron was absorbed when DK-4040 was treated with 3 kg B and 150 kg N ha^{-1} and minimum (34.87 ppm) was absorbed when there was no boron and nitrogen application. A significant interaction between nitrogen, boron and hybrid lead to the highest boron concentration in leaf. The concentration of B in sunflower leaves might be increased by the formation of polyol-B-polyol complexes that are phloem translocated and occur mainly in polyols (sorbitol, manitol) producing plants species (Boaretto et al., 2006). Ceyhan et al. (2008) found significant differences among different genotypes for leaf boron.

Table 5: *Leaf boron, oil and protein contents of sunflower as affected by combined application of nitrogen and boron.*

Treatments	Leaf boron content (mg kg^{-1})	Oil content (%)	Protein content (%)
Hybrids (H)			
H_1 (Hysun-33)	40.92 b	34.59 b	16.92 b
H_2 (DK-4040)	41.76 a	35.53 a	19.33 a
LSD (5%)	0.026	0.01	0.162
Nitrogen levels (N)			
N_0 (kg ha^{-1})	40.93 b	37.25 a	15.89 b
N_1 (kg ha^{-1})	41.75 a	32.87 b	20.36 a
LSD (5%)	0.026	0.010	0.162
Boron levels (B)			
B_0 (kg ha^{-1})	35.59 c	32.29 b	16.24 c
B_1 (kg ha^{-1})	40.46 b	36.56 a	19.30 a
B_2 (kg ha^{-1})	47.97 a	36.32 c	18.83 b
LSD (5%)	0.031	0.01	0.198
H x B x N			
H_1 x B_0 x N_0	34.60 i	33.20 i	13.32 i
H_1 x B_0 x N_1	35.14 k	30.51 k	16.14 g
H_1 x B_1 x N_0	40.31 g	38.49 d	14.08 h
H_1 x B_1 x N_1	39.51 h	33.40 h	22.38 a
H_1 x B_2 x N_0	47.24 c	38.52 c	13.65 i
H_1 x B_2 x N_1	48.71 b	33.40 h	21.95 bc
H_2 x B_0 x N_0	36.21 j	33.85 g	17.71 f
H_2 x B_0 x N_1	36.40 i	31.60 j	17.81 ef
H_2 x B_1 x N_0	41.32 e	40.18 a	18.45 d
H_2 x B_1 x N_1	40.71 f	34.18 e	22.31 ab
H_2 x B_2 x N_0	45.92 d	39.27 b	18.12 de
H_2 x B_2 x N_1	50.03 a	34.10 f	21.6 c
LSD	0.063	0.01	0.396

Means not sharing the same letters differ significantly at 5 % probability.
Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Nitrogen levels (N) N_0 = 0 kg ha^{-1}, N_1 = 150 kg ha^{-1} Boron levels (B) = Bo = 0 kg ha^{-1}, B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}.

Quality parameters

Table 5 showed that oil contents of sunflower were affected by both the hybrids (H_1 and H_2). Maximum oil contents (35.53%) were produced by Hysun-33 while DK-4040 produced (34.59%) percent. Data on oil contents showed that oil contents of sunflower were significantly affected by the application of different nitrogen and boron levels as well as different interactions (H × B), (B × N), (H × N), and highest order interaction. In case of nitrogen level N_0 (control), oil contents were maximum (37.25%) and minimum oil contents were recorded (32.87%) in case of N_1 level (150 kg ha^{-1}). Boron level B_1 (2 kg ha^{-1}) produced maximum oil contents (36.56 %) and minimum oil contents (32.29%) were recorded in control (B_0). For hybrid and nitrogen interaction (H×N) the treatment H_2N_0 (Hysun-33 and 0 kg ha^{-1} N) produced maximum oil content (37.72%). In case of boron and nitrogen interaction (B×N), the treatment B_1N_0 was found best which produced maximum oil content (39.34%) and minimum oil content (31.06%) was observed in B_0N_1 (0 kg ha^{-1} B and 0 kg ha^{-1} N). For hybrid, boron and nitrogen interaction (H×B×N) significantly maximum oil content (40.18%) was recorded when DK-4040 was grown with 2 kg B ha^{-1} without N application (control) and minimum oil content (31.60%) was found in DK-4040 when it was applied with 0 kg B and 150 kg N ha^{-1}.

The data pertaining to the sunflower achene protein contents are presented in the Table 5. Protein contents were affected by both hybrids (H_1 and H_2). Maximum protein content (19.33%) was produced by DK-4040 while Hysun-33 produced 16.92 percent. The data show that nitrogen and boron affected protein contents of sunflower and all the interactions among different hybrid, boron and nitrogen levels were found to be significant. Protein contents were maximum (20.36%) in N_1 (150 kg ha^{-1}) treatment and minimum (15.89%) in control (0 kg N ha^{-1}). In case of boron levels, boron level B_1 (2 kg ha^{-1}) produced maximum protein contents (19.30%) whereas control (0 kg ha^{-1}) gave minimum protein contents (16.24%). As far as hybrid and boron interaction is concerned, H_2B_1 gave maximum protein content (20.38%) and minimum protein content (14.73%) was given by H_1B_0 (hybrid Hysun-33 and 0 kg ha^{-1} B). For hybrid x nitrogen interaction, H_2N_1 (Hybrid DK-4040 and 150 kg ha^{-1} N) produced maximum protein content (20.57%) and minimum (13.68%) was observed in H_1N_0. In case boron and nitrogen interaction (B×N) maximum protein content (22.34%) was produced by treatment B_1N_1 while B_0N_0 produced 15.51 percent achene protein. Among hybrid, boron, and nitrogen interaction (H×B×N) significantly maximum protein content (22.38%) was produced when Hysun-33 was supplied with 2 kg 150 kg N ha^{-1} while minimum protein content (13.32 %) was found in Hysun-33 when it was grown without application of B and N.

The enhanced uptake of boron positively affected the oil content of sunflower. This might be due to after pollination and seed set, the formation of protein start and there after oil synthesis start. These results are coinciding with the finding of Ahmad et al. (2005). Oyinlola (2007) found that B levels and hybrids had significant effect on oil content. The quality of oil seeds is also determined by the protein contents in it. Dietary value and quality of sunflower achene may be indicated by the presence of protein contents. Now a day's all the nations are concentrating the balance in diet which can be obtained by producing quality oil and protein. These results are according to the findings as reported by Zahoor et al. (2011). This might be due to the high uptake of nitrogen by seed for application of boron and this nitrogen have been succeeding merging in the molecule of protein. Adequate application of nitrogen develops the protein precursors, due to which maximum photosynthates utilized for protein synthesis, while lesser amount is accessible for fats synthesis (Ahmad et al., 2007). Maragatham and Chellamuthu (2000) also reported increase in protein contents with increasing nitrogen rates.

Agronomic nitrogen use efficiency

Agronomic nitrogen use efficiency was not affected significantly by both the hybrids (table 6). Data show that nitrogen level N_1 (150 kg ha^{-1}) gave maximum value (5.35 kg kg^{-1}). Boron level B_1 (2 kg ha^{-1}) gave maximum value (3.08 kg kg^{-1}) and minimum value of agronomic nitrogen use efficiency (2.12 kg kg^{-1}) was recorded in control treatment. The interaction of nitrogen and boron (N×B) in case of agronomic nitrogen use efficiency was found to be significant (Table 6). For nitrogen and boron interaction, maximum value (6.16 kg kg^{-1}) of agronomic nitrogen use efficiency was given by the treatment B_1N_1 and minimum (0.00 kg kg^{-1}) was found in treatments B_0N_0 (control) B_2N_0 and B_1N_0 where no nitrogen was applied. Similar findings were also reported by Koutroubas et al. (2009) and Montemurro and Giorgio (2005).

Physiological nitrogen use efficiency

Data in Table 6 show that both the hybrids (H_1=Hysun-33 and H_2=DK-4040) had no effect on physiological nitrogen use efficiency. Physiological nitrogen use efficiency was affected by different nitrogen and boron levels. Maximum value of physiological nitrogen use efficiency (19.12 kg kg^{-1}) was recorded in the treatment N_1 (150 kg ha^{-1}) and minimum value (11.16 kg kg^{-1}) was recorded in control treatment N_0 (0 kg N ha^{-1}). The interactions between hybrid and boron, hybrid and nitrogen, and boron and nitrogen were found to be significant. Hybrid × nitrogen interaction shows that maximum value of physiological nitrogen use efficiency (23.28 kg kg^{-1}) was attained when DK-4040 was fertilized with 150 kg N ha^{-1} as against minimum (9.35 kg kg^{-1}) in control for DK-4040 respectively. For boron × nitrogen interaction, maximum value (27.88 kg kg^{-1}) of physiological nitrogen use efficiency was given by the treatment B_0N_1 (0 kg B ha^{-1} with 150 kg N ha^{-1}) and minimum (0.00 kg kg^{-1}) was found in treatment B_0N_0 (control) Data on hybrid and boron interaction show that maximum value (17.30) was obtained in treatment H_2B_0 (DK-4040 and 0 kg B ha^{-1}) and minimum (15.50) was given by H_1B_1 that was at par with rest of the treatments.

Table 6: *Agronomic and nitrogen use efficiency and physiological use efficiency of sunflower as affected by interactive effect of nitrogen and boron.*

Treatments	Agronomic nitrogen use efficiency (kg kg^{-1})	Physiological nitrogen use efficiency (kg kg^{-1})
Hybrids (H)		
H_1 (Hysun-33)	2.67	13.96
H_2 (DK-4040)	2.67	16.32
LSD (5%)	NS	NS
Nitrogen levels (N)		
N_0 (kg ha^{-1})	-	11.16 b
N_1 (kg ha^{-1})	5.35 a	19.12 a
LSD (5%)	0.085	2.64
Boron levels (B)		
B_0 (kg ha^{-1})	2.12 c	13.94
B_1 (kg ha^{-1})	3.08 a	15.55
B_2 (kg ha^{-1})	2.82 b	15.93
LSD (5%)	0.105	NS
H x B		
H_1 x B_0	2.13	10.57 b
H_1 x B_1	3.08	15.50 a
H_1 x B_2	2.80	15.82 a
H_2 x B_0	2.10	17.30 a
H_2 x B_1	3.07	15.61 a
H_2 x B_2	2.84	16.04 a
LSD (5%)	NS	4.57
H x N		
H_1 x N_0	-	12.97 bc
H_1 x N_1	5.35	14.96 b
H_2 x N_0	-	9.35 c
H_2 x N_1	5.34	23.28 b
LSD (5%)	NS	3.73
B x N		
B_0 x N_0	-	-
B_0 x N_1	4.24 c	27.88 a
B_1 x N_0	-	16.56 b
B_1 x N_1	6.16 a	14.55 b
B_2 x N_0	-	16.92 b
B_2 x N_1	5.64 b	14.95 b
LSD (5%)	0.148	4.57

Means not sharing the same letters differ significantly at 5 % probability.
Hybrids (H) H_1 = Hysun-33, H_2 = DK-4040, Nitrogen levels (N) N_0 = 0 kg ha^{-1}, N_1 = 150 kg ha^{-1} Boron levels (B) = Bo = 0 kg ha^{-1}, B_1 = 2 kg ha^{-1}, B_2 = 3 kg ha^{-1}. NS= Non significant

Table 7: *Effect of different nitrogen and boron levels on net income and benefit cost ratio of sunflower.*

Treatments	Total expenditure (Rs. ha^{-1})	Gross Income (Rs. ha^{-1})	Net Income (Rs. ha^{-1})	Benefit cost ratio
$H_1B_0N_0$	61785	122000	60215	0.97
$H_1B_0N_1$	67922	147640	79718	1.17
$H_1B_1N_0$	64385	127200	62815	0.97
$H_1B_1N_1$	70522	159040	88518	1.25
$H_1B_2N_0$	65585	124880	59295	0.90
$H_1B_2N_1$	71722	155680	83958	1.17
$H_2B_0N_0$	61785	113680	51895	0.83
$H_2B_0N_1$	67922	139000	71078	1.04
$H_2B_1N_0$	64385	117160	52775	0.81
$H_2B_1N_1$	70522	150560	80038	1.13
$H_2B_2N_0$	65585	115760	50175	0.76
$H_2B_2N_1$	71722	147760	76038	1.06

H_1=Hysun-33; B_0=0 kg ha^{-1}; N_0=0 kg ha^{-1}; H_2=DK-4040; B_1=2 kg ha^{-1}; N_1=150 kg ha^{-1}; B_2=3 kg ha^{-1}; Price of produce = Rs 1600/40kg

Economic analysis

Different nitrogen and boron levels along with their interactions resulted in different net income (Rs. ha^{-1}) as indicated in the Table 7. Treatment $H_1B_1N_1$ (Hysun-33 with 2 kg B + 150 kg N ha^{-1}) resulted in highest net income of Rs. 88518 while control gave the minimum net income of Rs. 60215. For benefit cost ratio, maximum benefit cost ratio (1.25) was also found in $H_1B_1N_1$ (Hysun-33, 2 kg ha^{-1} B, and 150 kg ha^{-1} N) where as it was 0.97 in control.

Author's Contribution

Muhammad Farrukh Saleem and Muhammad Tahir conceived the idea, wrote abstract and provided technical input at every step. Azhar Mehmood and Ali Zohaib conducted experiment, did overall management, collected data and wrote the introduction. Hafiz Tassawar Abbas did statistical analysis while Muhammad Aqeel sarwar and Tasawer Abbas wrote the remaining article.

Conclusion

In conclusion, the performance of sunflower hybrid, Hysun-33 in terms of higher growth, yield and oil contents was exhibited better in contrast to DK-4040. The contribution of nitrogen (150 kg ha-1) and boron (2 kg ha-1) in yield improvement of Hysun-33 was more prominent. The physiological as well as agronomic use efficiency was prominently increased with combined use of nitrogen and boron application. Based on BCR analysis, the highest net income (1.25) was obtained with interactive use of both nutrients.

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