The foliar feeding effects of plant growth promoting substances on wheat yield under organic and chemical soil amendments

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Submission: 9 August 2021 Revised: 6 June 2022 Accepted: 9 June 2022

ABSTRACT

A field experiment was conducted to assess the effect of the combined use of different soil amendments and foliar application of plants' hormone-like substances on the growth, yield, phenological and morpho-physiological traits of spring wheat in a semi-arid region at Maragheh in northwestern Iran (37° 23' N, 46° 16' E; 1,485 m) during the growing season of 2017–2018. Twelve treatments comprising factorial combinations of four kinds of fertilizers (no-application, humic acid at 20 kg ha^{-1}, farmyard manure at 20 t ha^{-1}, and chemical complete fertilizer contained 11 essential elements at 5 L ha^{-1}) and three growth regulators (distilled water as check, 200 ppm salicylic acid, and 200 ppm ascorbic acid) were compared in a spilt plot in randomized complete block design with three replications. The farmyard manure (FYM) was applied in the autumn and was ploughed down immediately after application. Results showed that FYM application significantly ($P < 0.01$) increased the plant growth and seed yield since the highest chlorophyll content (54.98 ± 1.96), number of days to anthesis (97.00 ± 4.33 days), canopy width (11.08 ± 0.36 cm), number of spikes per area (516.60 ± 89.62 spikes m^{-2}), number of glumes per spike (33.15 ± 3.84 glumes), seed protein content (13.72 ± 0.15%) and seed yield (4,353.30 ± 259.92 kg ha^{-1}) were recorded for plants grown under applied FYM. Assessment of phenological traits revealed that application of FYM delayed maturity. Although both foliar application of salicylic acid and ascorbic acid increased the studied characteristics compared to the control, the highest amount of 1,000-seed weight (46.34 ± 1.41 g), spike length (10.80 ± 1.09 mm), seed protein content (13.38 ± 0.16%), chlorophyll content (50.41 ± 2.36) and the amount of photoassimilate remobilized to the grain (3.72 ± 0.34 g plant^{-1}) was observed in plants sprayed with salicylic acid. Based on the obtained results, it can be suggested that due to the poor physicochemical conditions of the soil, the use of FYM in the studied site is necessary and has priority over other crop managements such as foliar application. However, foliar application of growth regulators, especially salicylic acid can improve plant growth and seed yield especially under farmyard applied conditions.

Keywords: Foliar spray, organic fertilizer, phenological traits, seed protein content, yield components

Thai J. Agric. Sci. (2022) Vol. 55(1): 20−33

INTRODUCTION

Wheat (*Triticum* spp.) is grown in different environments around the world and in fact it has the highest and widest adaptation among cereal crops to different climatic conditions. Wheat can be grown under both rainfed and irrigated conditions. Although the productivity of the area under irrigated wheat has increased during recent years, this has not had much effect on average production. Since the average cultivated area of irrigated wheat in Iran is about 39% and rainfed wheat is about 61% of the total area under wheat cultivation, improving irrigated wheat yield under favorable conditions has not been able to have a very positive effect on yield and total average wheat production (Pishbahar and Darparnian, 2016). Total wheat production in semi-arid regions is more affected by the yield of rainfed wheat. Where the Mediterranean semi-arid fields are subjected to severe risk of desertification due to poor and shallow soil and low organic matter content, water holding capacity, and plant nutrients. Soil organic matter and nutrients have been severely depleted owing to continuous cultivation and non-application of sufficient and proper fertilizers, ignoring of fallowing in crop rotations, and prevalence of severe erosion. The productivity of these soils has consequently declined. The enhancement of the soil organic matter status by regular addition of organic material is essential if adequate soil productivity is to be maintained (Janmohammadi *et al*., 2016). In addition, the situation is exacerbated by climate change. Water limitations and rising air temperatures are important components of future climate change scenarios for countries with dry climates (Vaghefi *et al*., 2019). In such situations agricultural practice may result in highly different properties and crop production in successive years, depending on annual metrological conditions. In these conditions, improving the physical and chemical properties of the soil is one of the main priorities for improving crop production.

Incorporating organic matter has several benefits for agricultural soils in semi-arid regions. It has the potential to improve the resilience of coarse-textured cropping soils to drying climates by increasing water infiltration, water-holding capacity, cation exchange capacity, and soil biological activity and improving nutrient cycling and helping to maintain soil nutrient status, in turn benefiting crop yield and its quality (Barton *et al*., 2016). Successive application of soil organic matter can also increase crop production and has the potential to lower crop fertilizer requirements. Because of the development of the livestock industry, farmyard manure (FYM) is an available, relatively cheap, and potential source of multiple nutrients for improving soil chemical, physical and biological properties (Nouraein *et al*., 2019).

In addition, one of the ways to increase soil organic matter is to use humic substances. Humic substances in soils and sediments can be divided into three main fractions: humic acids, fulvic acids, and humin. Humic acid is the main component of humic substances and the most important component of soil organic matter (humus) and improves plant growth by increasing the supply and availability of elements. The greatest effect of humic acid is on root growth and stimulation of hormone-like activities in the plant (Khoram Ghahfarokhi *et al*., 2018). Between these build products from organic matter breakdown, special interest has been ascribed for many decades to humic acid which has shown a specific potential in reducing soil pH and improving soil fertility (Mindari *et al*., 2019). Application of humic acid also can help to break up clay compacted soils, ameliorate soil physical properties, facilitate the transferring of micronutrients from the soil to the plant, improve water retention, increase seed germination rate, improve water, air, and root penetration, and stimulate the development of microflora population in soils (Jahan *et al*., 2019).

In addition, it appears that some foliar spraying treatments can provide better plant growth in semi-arid conditions by stimulating defense mechanisms and growth encouragement (Gajc-Wolska *et al*., 2018). Out of various foliar sprays, the application of ascorbic acid and salicylic acid gained prominent roles in the alleviation of multiple stresses and improving plant growth. Ascorbic acid ($C_6H_8O_6$) is present in all living plant cells, the largest amounts being usually in the leaves and flowers, i.e., in actively growing parts and it acts as an antioxidant and anti-stress agent, and also can be considered as a signaling molecule in some plant physiological processes and defense mechanisms (Allahveran *et al*., 2018). Also, it can play critical roles in the biosynthesis of some phytohormones like gibberellins, ethylene, and abscisic acid and can accelerate cell division and differentiation (Barth *et al*., 2006). Salicylic acid and its derivatives as one of the plant hormones produced by the plant naturally and can stimulate the production of antioxidants, flowering, ion absorption, nutrient transfer, increasing the representation of CO_2 gas, controlling the movement of stomata, photo materials, gas exchange, and protein synthesis (Hassoon and Abduljabbar, 2019).

Although the effects of FYM and humic acid application, as well as foliar treatments, have been studied separately, the little comparison has been made between them in semi-arid regions. To attain this, it is essential to generate information by studying the response of wheat to the application of different organic and chemical fertilizers and foliar spray of plant growth regulators. Thus, the present study aimed to investigate the effects of foliar spry of salicylic acid and ascorbic acid as growth regulators and stimulating drought tolerance under farmyard manure, acid humic, and complete chemical fertilizers application on growth stage developments and morpho-physiological trait of wheat grown in the semi-arid region.

MATERIALS AND METHODS

Characteristics of Location

The experiment was performed over a growing year (September 2017 to May 2018) at the research farm of Maragheh University in northwest Iran. The field was located at 46°16’ E, 37°23’ N, at an altitude of 1,485 m from sea level. Maragheh is a representative of the highland semi-arid zone and, according to the updated classification of Köppen and Geiger, its climate is classified as BSk; cold semi-arid climate (Peel *et al*., 2007). The field soil had a loam texture with a pH of 7.53, the total organic carbon and the electrical conductivity (EC) content were 0.76% and 1.22 dS m^{-1}, respectively. The contents of macronutrients and physico-chemical characteristics are listed in Table 1. The field was left as fallow before the spring wheat.

Table 1 Physico-chemical properties of field soil (depth of 0–30 cm) in Maragheh, northwest Iran

Physico-chemical properties	Field soil
Soil texture	Sandy clay loam
Sand (%)	47.00
Silt (%)	24.00
Clay (%)	29.00
Field capacity (%)	27.40
Permanent wilting point (%)	13.90
Organic matter (%)	0.76
Electrical conductivity (ds m^{-1})	1.22
pH	7.53
Cation exchange capacity ($cmol_c$/kg)	25.80
Potassium (mg/kg)	516.30
Available phosphorus (mg/kg)	12.60
Total nitrogen (%)	0.09

Weather Course

Maragheh has an average annual precipitation of 353 mm, consisting of 73% of rain and 27% of snow. The average annual rainfall during the spring wheat growing season (March to July) was 181 mm, of which more than 89% was received from March to May. The average maximum and minimum temperatures during the growing season were 21°C and 8°C, respectively.

Field Trial Description

Twelve treatments comprising factorial combinations of four kinds of fertilizer (no-application, humic acid at 20 kg ha^{-1}, farmyard manure at 20 t ha^{-1}, and chemical complete fertilizer contained 11 essential elements at 5 L ha^{-1}) and three growth regulators (distilled water as check, 200 ppm salicylic acid, and 200 ppm ascorbic acid) were compared in a split-plot experiment, based on a randomized complete block design (RCBD) with three replications. Each plot was 4 m^2 (2 × 2 m) and with a distance of one meter between replicates. Wheat seeds of (cv. Sardari) were sown through hand drill on 10 rows with 20 cm row to row and 3 cm plant to plant spacing. This interval was considered to investigate the effect of treatments on canopy growth.

Foliar Spry

Salicylic acid (2-(HO) $C_6H_4CO_2H$), synonyms: 2-Hydroxybenzoic acid, with a molecular weight of 138.12 product of Sigma-Aldrich was applied. The L-enantiomer of ascorbic acid and conjugate acid of L-ascorbate ($C_6H_8O_6$) was used. Foliar spry was carried out during leaf development (BBCH-scale = 17; seven leaves unfolded), tillering (BBCH-scale = 21; beginning of tillering: first tiller detectable), stem elongation (BBCH-scale = 34; node 4 at least 2 cm above node 3), and heading (BBCH-scale = 55; middle of heading: half of inflorescence emerged). Spraying was continued until the whole plant was covered with droplets. To prevent evaporation, foliar spraying was done in the afternoon near sunset.

Fertilizer Characteristics

The chemical properties of FYM included 0.68% of total N, 0.44% of available P, and 1.08% of available K with a pH of 6.83. Humic acid was the by-product of mining and obtained by inorganic salts/solutions excluding ammonium salts. Water soluble powdered humic acid contained fluvic acid 12%, humic acid 68%, and potash 15%, which was applied as surface banding beside the ridges at 5 cm depth. Chemical complete fertilizer contained 11 essential elements (N = 5%, P = 3%, K = 3%, Fe = 4.5%, Zn = 0.8%, Ca = 6%, Mg = 6%, Mn = 0.7%, Cu = 0.65%, B = 0.1%, Mo = 0.65%). Chemical fertilizers were used as fertigation in three splits immediately after seed sowing, stem elongation, and heading. Tillage and manure application were performed in August. Planting was carried out one month after manure application. Sprinkler irrigation was applied in 8–10-day intervals. All the agronomic practices and manual weed control were followed as per the standard advised procedure for all treatments uniformly.

Measuring Leaf Chlorophyll Content

SPAD unit (indicative of chlorophyll content) was measured on ten leaves of a plant at each plot, using a portable chlorophyll meter (Minolta SPAD-502) at the beginning of the grain development stage. Plant height was recorded by the meter during the physiological maturity stage by measuring the height of the plant from the ground to the tip of the ear awns.

Harvesting

At the fully ripe stage (BBCH-scale = 89; grain hard, difficult to divide with thumbnail), yield components and morphological traits such as plant height, straw yield, spike length, number of grains per spike, 1,000-seed weight, and seed yield were evaluated. To determine the spike length, five spikes were randomly selected in each plot and their length was measured from the base of the rachis to the tip of the uppermost spikelet. The difference in stem dry weight during anthesis and fully ripe stage was considered as the amount of remobilization to grain.

Measuring Grain Protein

Seed protein was measured through a portable near-infrared seed analyzer (Zeltex). To study the rate of remobilization of assimilates, the dry weight of 20 randomly selected plants from each plot at the stages of anthesis and physiological maturity was obtained.

Statistical Analysis

The effects of fertilizers and growth regulators on evaluated morpho-anatomical, physiological traits were subjected to analysis of variance (ANOVA). Traits were statistically analyzed using ANOVA based on a split-plot in the RCBD model and means among treatments were compared using the least significant difference (LSD) at 1% and 5% of probability level (Snedecor and Cochran, 1990).

RESULTS AND DISCUSSION

Morphological Traits

Plant height

Variance analysis revealed that fertilizer treatment significantly affected the plant height ($P < 0.05$). The tallest plants were obtained by applying FYM (64.62 ± 0.68 cm) and chemical fertilizer (66.37 ± 2.76 cm). The application of chemical fertilizer increased the plant height by about 11.6% compared to the control (57.21 ± 4.44 cm). However, the foliar application could not affect the plant height (Table 2). Although most of the changes in height are due to hormonal changes, especially auxin and gibberellin, it seems that foliar treatments could not have significant changes in the biosynthesis or release of these hormones. The application of chemical fertilizers with the rapid supply of essential elements for growth was able to improve plant height (Kobua *et al*., 2021). The results showed a significant effect of fertilizer treatments for most of the study traits. With regards to collected data on soil physicochemical parameters (Table 1) and severe deficiency of some essential macronutrients and organic matter, it seems that any supply of nutrient elements in the soil can rapidly affect plant growth and improve plant productivity.

Canopy width

Evaluation of canopy width showed that the interaction effect of fertilizer × foliar spray was significant for this trait ($P < 0.05$). The mean comparison showed that under no fertilization condition (control) spray of ascorbic acid significantly increased canopy width (9.71 ± 1.62 cm). However, under the application of organic and chemical fertilizers, the highest canopy width was obtained by spraying salicylic acid (humic acid: 9.24 ± 0.87 cm, FYM: 12.34 ± 1.24 cm, chemical fertilizer: 8.19 ± 2.31 cm). The results showed that the positive effects of salicylic acid are to some extent dependent on nutritional conditions. The maximum canopy width was related to plants grown under the application of FYM and chemical fertilizers (Figure 1A). The effect of FYM application on vegetative growth traits such as ground coverage by canopy was much more evident than other fertilizer treatments.

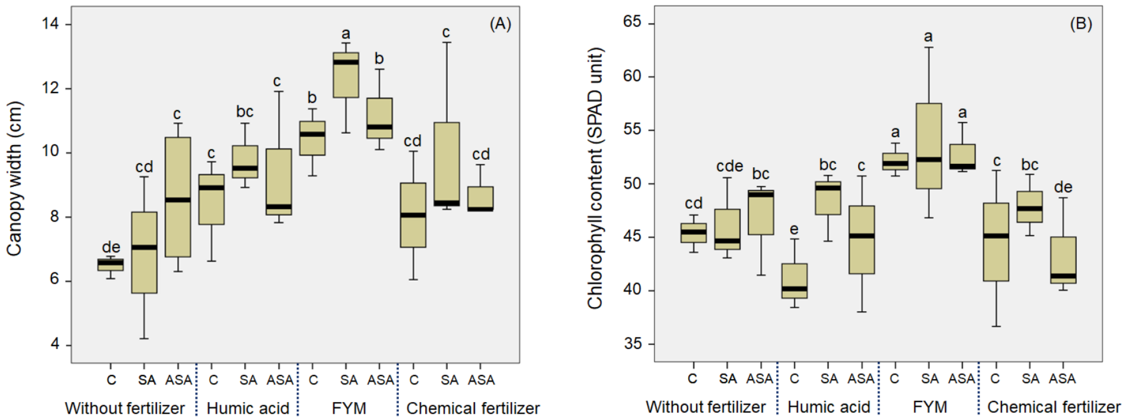

Figure 1 Impacts of different fertilizer and foliar spray of growth regulators on canopy width of wheat plants (A) and chlorophyll content in wheat leaves (B) cultivated in the highland semi-arid region of Maragheh. C = foliar application of distilled water as control, SA = foliar spray of salicylic acid, ASA = foliar spray of ascorbic acid, FYM = farmyard manure. Different letters indicate significant differences between treatments at $P < 0.05$.

Table 2 Effect of different fertilizers and foliar spray of growth regulators on some morphological traits of wheat

Factor	PH	CW	GC	CHL	DB	DA	DM	STY	AWL
Fertilizer (F)	*	**	*	**	NS	*	*	*	NS
Without fertilizer	57.21 ± 4.44^{b}	8.27 ± 1.95^{b}	61.78 ± 6.53^{c}	44.70 ± 1.33^{c}	83.62 ± 2.30	86.66 ± 2.02^{c}	116.22 ± 1.66^{bc}	4,240.7 ± 93.3^{c}	6.30 ± 0.26
Humic acid	61.48 ± 3.75^{ab}	7.66 ± 1.48^{b}	73.78 ± 3.33^{bc}	46.07 ± 2.17^{b}	89.11 ± 1.53	92.66 ± 1.00^{b}	119.55 ± 1.33^{b}	4,408.6 ± 189.2^{bc}	6.21 ± 0.14
FYM	64.62 ± 0.68^{a}	11.08 ± 0.36^{a}	79.33 ± 8.33^{a}	54.98 ± 1.96^{a}	88.22 ± 3.71	97.00 ± 4.33^{a}	123.33 ± 3.33^{a}	4,834.7 ± 170.3^{a}	5.70 ± 0.13
Chemical fertilizer	66.37 ± 2.76^{a}	8.42 ± 1.85^{b}	78.00 ± 6.66^{a}	49.38 ± 1.01^{ab}	83.66 ± 2.30	94.00 ± 1.33^{ab}	117.33 ± 2.00^{b}	4,618.7 ± 156.7^{b}	5.64 ± 0.77
Foliar spray (FS)	NS	NS	NS	*	NS	NS	*	NS	NS
Control	62.49 ± 3.10	8.90 ± 0.98	79.25 ± 8.33	45.07 ± 1.20^{b}	83.75 ± 2.00	93.16 ± 3.01	117.58 ± 1.23^{b}	4,460.0 ± 217.3	6.10 ± 0.55
salicylic acid	62.80 ± 2.71	8.62 ± 1.16	71.58 ± 4.66	50.41 ± 2.36^{a}	88.41 ± 1.80	93.00 ± 3.03	123.41 ± 2.00^{a}	4,798.0 ± 289.3	5.74 ± 0.11
ascorbic acid	61.98 ± 2.08	9.04 ± 1.70	68.00 ± 6.33	48.75 ± 2.18^{ab}	82.08 ± 2.33	92.50 ± 2.78	118.00 ± 1.66^{b}	4,525.0 ± 156.2	6.06 ± 0.27
F × FS	NS	*	*	**	NS	NS	NS	NS	NS

Note: PH = plant height (cm), CW = canopy width (cm), GC = ground coverage by canopy (%), CHL = chlorophyll content (SPAD unit), DB = number of days to boot stage, DA = number of days to anthesis, DM = number of days to maturity, STY = straw yield (kg ha^{-1}), AWL = length of the awn (cm). Values show mean ± standard deviation of each evaluated trait. Mean values of the same category followed by different letters are significant at $P < 0.05$ level. NS = not significant, * significant at 5% level of probability, ** significant at 1% level of probability.

Although the application of all fertilizer treatments was able to improve canopy growth compared to the control, the efficiency of organic fertilizers, especially FYM, was higher than other fertilizers. This indicated the importance of improving soil organic matter in this region. One of the reasons for the deficiency of soil organic matter in the mentioned region is overgrazing and lack of proper crop rotation. In much of the area, crops and pastures for sheep are grown on the same properties. The common rotation is based on the continuous cultivation of cereals (wheat and barley). In cases where fallow is considered, it is usually not associated with other crop management during fallow. When comparing our results to those of older studies, it must be pointed out that the application of FYM could improve the mean weight diameter of aggregates, total porosity, and water holding capacity of soils (Nouraein *et al*., 2019). The applications of organic materials and inorganic fertilizers have significantly enhanced grain yields and water use when compared to no additives or the addition of only inorganic N and P (Mahmood *et al*., 2017; Sadaf *et al*., 2017). Another key fact to remember the application of FYM by restoring the physico-chemical properties of the soil facilitates the uptake of elements by the roots. A similar conclusion was reached by Hasnain *et al*. (2020).

Chlorophyll content

The chlorophyll content in upper leaves noticeably responded to fertilizer treatment and foliar sprays (Table 2). Also, the interaction effect of fertilizer × foliar spray was significant on chlorophyll content ($P < 0.01$). The highest SPAD units were recorded for plants grown with the application of FYM (54.98 ± 1.96; Table 2). Under no fertilization condition (control), foliar spray of ascorbic acid caused a significant increase in chlorophyll content (49.23 ± 2.34). However, under humic acid and chemical fertilizer application conditions, the salicylic acid foliar application had a greater effect on improving chlorophyll content (Figure 1B). Although the highest chlorophyll content was obtained with the application of FYM, no significant difference was observed between foliar spraying treatments.

The chlorophyll content is highly dependent on plant nutritional status and nitrogen supply (Fiorentini *et al*., 2019). It has been revealed that the changing trend of photosynthetic rate and stomatal conductance was consistent with the chlorophyll content (Wang, 2010). Our data suggest that fertilizer and foliar treatments can improve source strength and increase the supply of photoassimilates to growing sinks. Due to unfavorable soil conditions in semi-arid regions, the reason may be that organic fertilizer can improve soil total porosity and nutrient status and it ensures the absorption and utilization of water by the roots of plants. Furthermore, fertilizer and foliar spray treatments simultaneously increased the sink size so that the number of grains per spike increased with the application of humic acid and FYM. It appears that choosing the suitable fertilizer and foliar sprays can increase seed yield by improvement of vegetative growth and by creating and maintaining an appropriate source; sink balance (balance between the assimilate production in photosynthesis and the assimilate utilization for grain yield). Also, our results showed that the application of fertilizers, especially FYM along with a salicylic acid spray could significantly increase the chlorophyll content. The findings are directly in line with previous findings (Janmohammadi *et al*., 2014; Fiorentini *et al*., 2019).

Phenological Traits

Some phenological traits such as the number of days to anthesis ($P < 0.05$) and number of days to maturity ($P < 0.05$) were affected by fertilizer treatments (Table 2). In general, the applications of chemical and organic fertilizers compared to the control delayed anthesis and maturity stage. The longest vegetative development period (number of days from sowing to anthesis) was recorded for plants grown under FYM application conditions (97.00 ± 4.33 days). However, neither fertilizer treatments nor foliar sprays could affect the days to booting stage statistically (Table 2).

Straw yield and length of the awn

Evaluation of straw yield showed that this trait was significantly affected by fertilizer management ($P < 0.05$). On average, the use of organic or chemical fertilizers increased straw yield by 10% over the no fertilization condition (humic acid: 4,408.6 ± 189.2 kg ha^{-1}, FYM: 4,834.7 ± 170.3 kg ha^{-1}, chemical fertilizer: 4,618.7 ± 156.7 kg ha^{-1}). However, the length of the awn was not affected by fertilizer or foliar spray treatments (Table 2). This indicated the stability of this trait against management treatments and probably this trait is strictly under genetic control.

Seed yield and yield components

The interaction between fertilizer and foliar spray of growth regulators significantly affected seed yield ($P < 0.05$; Figure 2). Evaluations of seed yield and yield components are presented in Table 3. Fertilizer application affected the grain length significantly ($P < 0.05$). However, among the fertilizer treatments, only the application of FYM (8.12 ± 0.20 mm) could increase the grain length by 9%. The grain length of plants grown under foliar conditions was not significantly different. A relatively similar trend was observed for spike length. Spike length in plants grown under FYM (11.80 ± 0.57 mm) was 14% longer than those grown without fertilizer. Spike weight was considerably improved by the application of FYM or chemical fertilizers. An example of this is the study carried out by Janmohammadi *et al.* (2014) in which lentil yield components significantly responded to FYM.

Assessment of seed number per spike showed that both fertilizer and foliar spray had significant effects on this trait (Table 3). The highest seed number per spike was related to plants grown under FYM and foliar application of salicylic acid. The number of fertile tillers was also affected by both factors. Although the use of chemical fertilizers and humic acid was able to significantly increase the number of spikes per square meter, the use of FYM increased the number of spikes per square meter by 29%. Application of FYM increased glume number in spike by 20% over the control. However, evaluation of 1,000-seed weight showed that the highest seed weight was recorded for plants grown by application of chemical fertilizer and sprayed with salicylic acid. This view is supported by Khoram Ghahfarokhi *et al*. (2018) who showed that chemical fertilizer has prompt effects on seed yield components in the semi-arid region.

Table 3 The effects of fertilizers and foliar sprays effects on yield component and protein content of wheat in the semi-arid region in northwest Iran

Factor	GL	SL	SPW	SNS	SNP	GLN	TSW	REM	PRO
Fertilizer (F)	*	*	**	*	*	**	*	*	*
Without fertilizer	7.41 ± 0.13^{b}	10.33 ± 1.24^{ab}	1.87 ± 0.43^{c}	24.03 ± 3.14^{b}	377.33 ± 25.63^{c}	27.26 ± 2.69^{b}	44.24 ± 0.89^{b}	2.54 ± 0.28^{b}	12.16 ± 0.26^{c}
Humic acid	7.93 ± 0.31^{ab}	10.05 ± 0.67^{b}	2.07 ± 0.23^{ab}	27.21 ± 2.41^{b}	403.30 ± 23.60^{b}	26.80 ± 2.81^{b}	45.91 ± 0.23^{bc}	4.42 ± 0.34^{a}	13.12 ± 0.18^{b}
FYM	8.12 ± 0.20^{a}	11.80 ± 0.57^{a}	2.14 ± 0.16^{a}	31.70 ± 1.27^{a}	516.60 ± 89.62^{a}	33.15 ± 3.84^{a}	43.06 ± 0.76^{c}	2.72 ± 1.19^{ab}	13.72 ± 0.15^{a}
Chemical fertilizer	7.51 ± 0.08^{b}	10.27 ± 1.46^{ab}	2.17 ± 0.11^{a}	27.68 ± 1.93^{b}	443.33 ± 53.24^{b}	28.93 ± 3.17^{b}	46.08 ± 0.34^{a}	3.77 ± 1.01^{ab}	13.08 ± 0.23^{b}
Foliar spray (FS)	NS	NS	NS	*	NS	NS	NS	NS	*
Control	8.10 ± 0.12	10.70 ± 1.18	2.11 ± 0.30	26.81 ± 1.56^{b}	447.17 ± 15.24	29.24 ± 1.66	45.23 ± 0.18	3.51 ± 0.93	12.71 ± 0.15^{b}
salicylic acid	7.90 ± 0.23	10.80 ± 1.09	2.05 ± 0.51	29.48 ± 1.28^{a}	454.17 ± 34.17	31.74 ± 2.85	46.34 ± 1.41	3.72 ± 0.34	13.38 ± 0.16^{a}
ascorbic acid	7.81 ± 0.10	10.34 ± 1.02	2.03 ± 0.22	27.68 ± 0.83^{b}	419.17 ± 38.24	29.82 ± 2.31	44.05 ± 0.68	2.87 ± 0.24	12.96 ± 0.07^{ab}
F × FS	NS	NS	NS	*	*	NS	*	**	**

Note: GL = grain length (mm), SL = spike length (mm), SPW = spike weight (g), SNS = number of seeds per spike, SNP = number of spikes per square meter, GLN = number of glumes per spike, TSW = weight of one thousand seeds (g), REM = rate of remobilization from stem to seed (g $plant^{-1}$), PRO = seed protein content (%). Values show mean ± standard deviation of each evaluated trait. Mean values of the same category followed by different letters are significant at $P < 0.05$ level. NS = not significant, * significant at 5% level of probability, ** significant at 1% level of probability

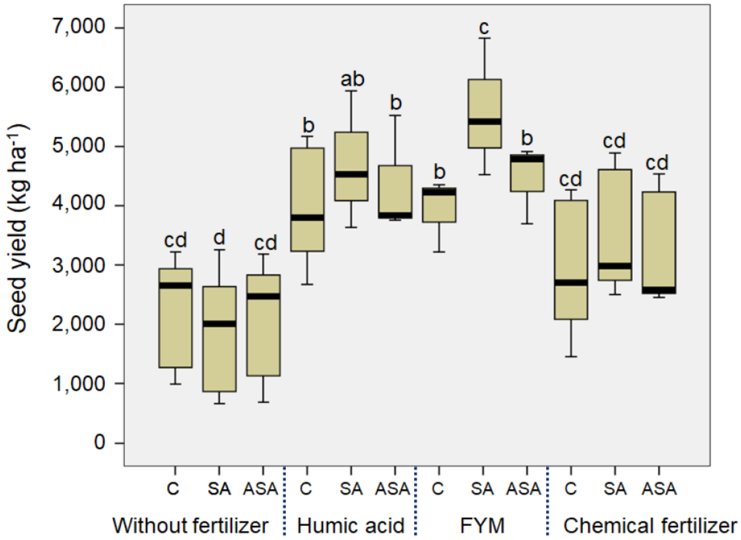

Figure 2 Impacts of different fertilizer and foliar spray of growth regulators on seed yield of wheat plants cultivated in the highland semi-arid region of Maragheh. C = foliar application of distilled water as control, SA = foliar spray of salicylic acid, ASA = foliar spray of ascorbic acid, FYM = farmyard manure. Different letters indicate significant differences between treatments at $P < 0.05$.

Interestingly, the lowest grain weight was observed under the application of FYM and foliar spray of ascorbic acid. The results of traits demonstrated two things. First, fertilizer management especially FYM and foliar application of growth regulators increased the vegetative growth parameter like plant height, canopy width, and ground coverage by the canopy. Second, the application of fertilizer significantly improved the seed yield components. The results confirmed that fertilizer treatments impressed the sink-source relationships.

Remobilization from stem to seed

The interaction effect between foliar application and fertilizer management significantly affected remobilization rate ($P < 0.01$). Evaluation of remobilization from stem to seed showed that although the foliar application of salicylic acid under non-fertilization (4.07 ± 0.67 g plant^{-1}) and chemical fertilizer application conditions (5.63 ± 1.04 g plant^{-1}) stimulated the remobilization of the photoassimilates considerably, under the application of organic fertilizers the highest remobilization was related to plants grown without foliar application of growth regulators (Figure 3A).

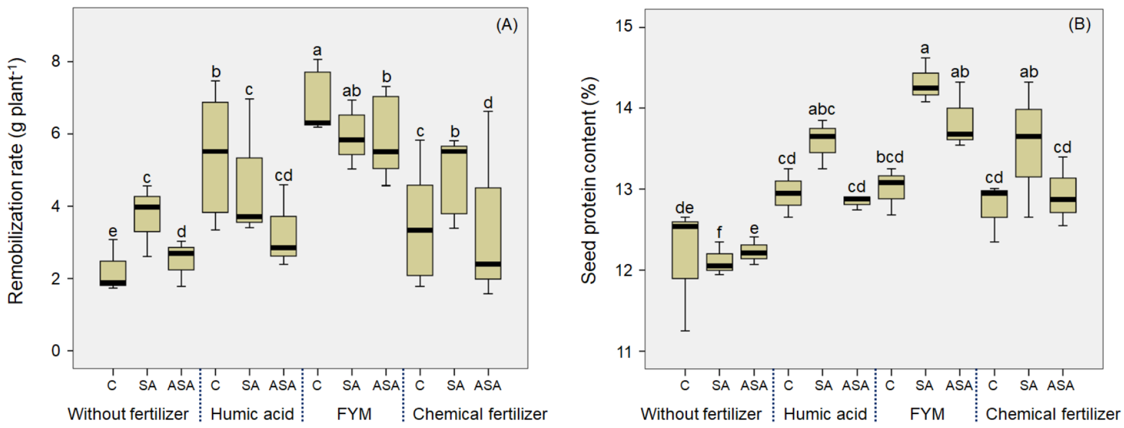

Figure 3 Impact of different fertilizer and foliar spray of growth regulators on rate of remobilization from stem to seed after anthesis (A) and seed protein content (B) in wheat plants cultivated in the highland semi-arid region of Maragheh. C = foliar application of distilled water as control, SA = foliar spray of salicylic acid, ASA = foliar spray of ascorbic acid, FYM = farmyard manure. Different letters indicate significant differences between treatments at $P < 0.05$.

Plant's growth depends on the conversion of solar energy into chemical energy via photosynthesis in source organs, mainly mature leaves and the green parts contain chlorophyll and photosynthesis (source), to form carbohydrates and translocate photoassimilates, mainly sucrose, to sink organs such as young leaves, roots, stems, flowers, and fruits (sink) for their utilization (Wang *et al*., 2020). From these results, it is clear that fertilizer application and foliar spray increased the size of the source, these include increasing the width of the canopy and the percentage of ground cover. It could simply mean that the application of FYM and foliar spray of salicylic acid by improving soil conditions, providing nutritional requirements, and creating favorable conditions for plant growth have enabled the development of vegetative organs. Increasing the length of the vegetative growing period and producing more straw yield also confirms this.

Seed protein content

Results demonstrated a strong effect of fertilizers on seed protein content ($P < 0.05$). Examination of seed protein content showed that the application of chemical and organic fertilizers significantly increased the protein content (humic acid: 13.12 ± 0.18%, FYM: 13.72 ± 0.15%, chemical fertilizer: 13.08 ± 0.23%). The effect of foliar application of growth regulators under fertilizer applied conditions was quite evident. The highest effect of foliar treatments was related to salicylic acid (Figure 3B). The effect of ascorbic acid application on this trait was more under FYM conditions when compared with other fertilizer treatments. These results confirm that under effective nutritional conditions, the effectiveness of ascorbic acid was significantly increased. Stimulation of seed protein through plant hormones might probably depend largely on the availability of nutrients and the application of FYM might provide the best nutritional conditions.

The amount of grain protein, one of the important quality aspects, can affect the health of the community. The amount of grain protein is strongly affected by nitrogen supply in the form of remobilization from leaves and stems. It seems that the application of FYM and humic acid by improving plant growth and increasing photosynthesis in the pre-anthesis period has increased the storage of photoassimilates and nitrogen in the stem and these materials have been translated to growing seed during the filling stage. Improving nitrogen remobilization from vegetative tissues has the advantage of improving grain filling and grain protein content. However, there is typically a negative relationship between seed yield and protein content, no such relationship was observed in the present experiment. One way to solve the yield versus seed protein content dilemma and to decrease fertilizer use is to improve plant nitrogen management through manipulating nitrogen recycling and especially nitrogen remobilization from vegetative plant organs to the seeds. Our results showed that foliar application of salicylic acid improved the grain protein content may by stimulating nitrogen remobilization from stem to filling rains.

CONCLUSIONS

Soils in semi-arid regions and most of wheat fields in northwestern Iran face several soil limitations. Low organic matter is one of the most important problems of these soils and causes less effectiveness of other crop management in the field. Our finding showed that the use of any organic substances can stimulate growth and improve yield compared to the control. However, the application of FYM was more effective than the humic acid substance. The results showed that the efficiency of chemical fertilizers before improving the physical and chemical condition of the soil is very low and in some cases is insignificant. Foliar application of salicylic acid and ascorbic acid increased chlorophyll content and canopy width and slightly improved seed yield. The overall effectiveness of the fertilizer treatments was much more significant than foliar application. The best results were observed under FYM applied conditions along with the salicylic acid foliar application. Improving soil conditions is one of the main priorities for wheat production in the studied conditions.

ACKNOWLEDGEMENTS

The authors are highly grateful to H. Kouchakkhani and A. Ahadnezhad for their technical assistance. This paper is an output of a project funded by the University of Maragheh and the Ministry of Science, Research and Technology. The authors would like to thank the experts of Central Laboratory (depended on the Laboratory Network of Strategic Technologies) for their assistance in laboratory analysis.

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