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EFFECT OF NANO-SILICON FOLIAR APPLICATION ON SAFFLOWER GROWTH UNDER ORGANIC AND INORGANIC FERTILIZER REGIMES

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Abstract

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Silicon nanoparticles have distinctive physicochemical characteristics and are able to enter into plants and impact the metabolism of plants as well as improve plant growth and yield under unfavourable environmental conditions. Besides, low soil organic matter content, imbalanced nutrient and inadequate water supply may adversely affect crop productivity in semiarid areas. To understand the effects of foliar spray of silicon dioxide nanoparticles ($nSiO_2$) with application of farmyard manure (FYM) or inorganic fertilizer on morpho-physiological traits and yield of safflower, a field experiment was carried out in a highland semiarid region of Maragheh, northwest Iran. The experiment consisted of two levels of $nSiO_2$ (0 and 20 mM) and four fertilizer regimes (control, 15 t ha^{-1} FYM, 30 t ha^{-1} FYM, 90 kg ha^{-1} N-P-K chemical fertilizer). Safflower plants were treated with $nSiO_2$ suspension at leaf development, branching and capitulum emergence stages. Although the $nSiO_2$ significantly improved some growth parameters such as canopy spread, stem diameter, plant height, ground cover and the number of achenes in capitulum, it did not affect achene yield and harvest index. However, fertilizer treatments considerably affected most of morpho-physiological traits, achene yield and yield components. The result showed that the best growth and the highest achene yield were achieved by application of 30 t ha^{-1} FYM before sowing. Application of high FYM increased the achene yield by 48% compared to the control, however, application of N-P-K chemical fertilizer or of 15 t ha^{-1} FYM improved achene yield only up to 17% over the no fertilizer condition. Moreover, this work revealed some positive effects of exogenous application of $nSiO_2$ on safflower growth. This finding suggests that application of organic fertilizers with foliar spray of $nSiO_2$ can improve safflower production and is an advisable agronomic option.

Keywords: chemical fertilizer, exogenous application, farmyard manure, plant nutrients, silicon nanoparticles.

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is an annual, herbaceous, broadleaf oilseed crop from the Asteraceae family. Safflower is believed to have originated in southern Asia and it is commercially cultivated for vegetable oil extracted from the seeds. This plant can produce acceptable yield in the same regions that favour the development of wheat and barley and undoubtedly it is a crop with relatively untapped potential and wide range compatibility (Gilbert et al., 2008).To date, the estimated world production is about 647374 t of safflower achenes from an area of 728641 ha land (FAO, 2013).

In semiarid Mediterranean regions, water is the most important limiting factor for crop production and only a limited number of crops can be cultivated in these areas (Kepner et al., 2006). In dry land cropping systems with limited water resources, in addition to seed production, safflower can also be cultivated as a valuable forage crop (Weinberg et al., 2002). Because of effectual deep root and the many fine lateral roots safflower can considerably tolerate periods of moisture shortage, while this severity of the drought may significantly restrict the growth and yield of other crops. The best forage quality can be achieved from mid-budding to early blooming stage when it is not too prickly and, thus, remain highly palatable to livestock. In these regions foliage and stems of this plant can be utilized as green fodder, hay or silage (Landau et al., 2005).

Nutrient management plays an important role in the universal necessity to increase crop production and meet the food needs of the growing population. Fertilizer application affects crop productivity through plant morphological trait such as leaf area and rooting depth, which subsequently affect physiological process such as water absorption and transpiration (Marschner, 2012). However, the extents, to which fertilizers are applied, vary considerably between different regions and is strongly influenced by climatic conditions, crop species and cropping system. However, in rainfed farming systems, nutrient management is noticeably dictated by the amount of precipitation and stored soil moisture (Ryan et al., 2012). In semiarid regions, to moderate the adverse effect of terminal drought, soil needs to capture the precipitation that falls on it, store as much of that water as possible for future plant use, and provide conditions for plant roots to penetrate and proliferate (Bot & Benites, 2005).

It has often been argued that intensive application of chemical fertilizers began from Green Revolution especially to meet the high nutrient requirement of high-yielding varieties (Evenson & Gollin, 2003). Although the chemical fertilizers have some advantages, they also have some disadvantages such as high probability of leaching, high energy consumption for their production, risk of the toxic chemicals, stimulating the vegetative growth and depletion of soil water storage (Oslen, 1978). Though evidences about the positive effects of organic fertilizers on crop production in semiarid areas are rising, farmers in the region rely on short-term positive effects of chemical fertilizers to maintain crop yields, and pay little attention to maintaining soil organic matter in soils (Shirani et al., 2002). Farmyard manure is a mixture of animal dung and urine soaked waste plant materials, which is suitable for field crop fertilization (Kolay, 2007). Application of farmyard manure (FYM) can greatly improve the soil properties, which reduce the requirements for mineral fertilizers and improve organic matter balance, soil water and water-use efficiency (Shaxson & Barber, 2003; Rudrappa et al., 2006; Wang et al., 2013). The application of organic fertilizers in semiarid regions of Iran seems to be very imperative, because soils in these areas are intensively tilled; they are low in organic matter content and consequently have weak structural stabilities (Shirani et al., 2002). Furthermore, removal of straw for animal feed is common in semiarid regions and this may indicate the importance of application of organic fertilizers. It has been revealed that farmyard manure can supply all major macronutrients (N, P, K, Ca, Mg, S) essential for plant development (Jaga, 2013), as well as micronutrients (Fe, Mn, Cu and Zn). Also it can sustain soil nutrient concentration and stimulate various features of soil fertility (Satyanarayana et al., 2002).

Nanoparticles (NPs) are proposed to be the materials for the new millennium. Agricultural applications of beneficial nanoparticles are currently interesting fields of research (Karunakaran et al., 2013). The NPs interact with plants causing many morphological and physiological changes, depending on the properties particles. Among the NPs, nano-silicon has gained greater consideration during the last years. Silicon is plentiful in soils and the second most common element on earth after oxygen and has been recognized as a beneficial nutrient for plant growth and development (Wainwright, 1997; Siddiqui et al., 2015). It has been revealed that exogenous application of nano-silicon on plants enhances the plant growth and development by increasing accumulation of proline, free amino acids, content of nutrients, antioxidant enzymes activity, gas exchange and improve efficiency of photosynthetic apparatus (Xie et al.,2012; Kalteh et al., 2014). However, the effectiveness of the same nanoparticle is dissimilar in different plant species or under various environmental conditions (Prasad et al., 2012). There is little doubt that there has been less work to evaluate the effect of foliar spray of nano-silicon on growth and yield of safflower in semiarid regions. Therefore, this study initiated to generate new information on the efficacy of nanoscale silicon dioxide on the growth and development of safflower (*Carthamus tinctorius* L.) under different fertilizer management treatments.

MATERIALS AND METHODS

The safflower 'Esfahan' cultivar seed, a spring type, was used in this experiment for achene production, provided by the Seed and Plant Breeding Research Institute, Karaj, Iran. Field studies were conducted at the Experimental Farm of the College of Agriculture and the University of Maragheh, Iran (46^o16' E and 37^o23' N with an altitude of 1485 m) during 2015 cropping seasons. Maragheh is a representative of highland semiarid zone, and some climatic parameters obtained during this research are given in Table 1. The soil texture at the experimental site was sandy loam comprising of sand (53%), silt (31%) and clay (16%), pH 7.45, electrical conductivity (EC) = 0.506 dsm^{-1}, organic matter = 1.8 g kg^{-1}, nitrogen (N) = 0.058%, available phosphorus = 5.67 mg kg^{-1} and available potassium (K) = 342 mg kg^{-1}, total neutralizing value = 34%.

A 4 × 2 factorial experiment layout plan was arranged in a spilt-plot design based on a randomized complete block design with three replications. Four fertilizer regimes, including control, application of 30 t ha^{-1} farmyard manure (FYM1), application of 15 t ha^{-1} farmyard manure (FYM2) and application of 90 kg ha^{-1} N-P-K chemical fertilizer were assigned to the main plots, and two levels of $nSiO_2$ foliar application (0 and 20 Mm) were assigned to the subplots. The field was mouldboard-ploughed during autumn and twice disked before seed sowing. After opening of furrows, the seeds were hand planted on 14 April 2015. The seeds were sown in experimental plots of 4.0 m (length) × 3.0 m (width), with 12 rows 0.25 m apart from one another, with small terraces of 1.5 m in the interspaces to prevent contamination by surface run-off containing fertilizer. There was no incidence of pest or disease on plants during the experiment. The crop was kept free of weeds by hand hoeing when necessary. Plants were grown under rainfed condition with two supplemental irrigations during the reproductive stage. Decayed farmyard manure was uniformly applied on the surface and mixed to 15 cm depth by spade. Then the field was ridged or transformed to the row and inter-row. Chemical fertilizer was utilized as preplant surface band so that fertilizer was applied to the soil surface in a band along the side of row after seedbed preparation.

Nanoparticles of silica (SiO_2) were purchased from the Pishgaman Nano, Iran. According to the manufacturer, the particle sizes of SiO_2 ranged from 20 to 30 nm. Specific surface area of nanosized silica was 180–600 m^2 g^{-1} and purity was 99.7%. The result of X-ray analysis and transmission electron microscope (TEM) image of silicon dioxide approved that they were nano-sized particles (Janmohammadi & Sabaghnia, 2015).

Phenology can potentially be a powerful tool for monitoring the response of plant to exogenous treatment. Phenological growth phases were monitored at 1–2 day intervals throughout the season according to the BBCH scale described by Flemmer et al. (2015). Safflower plants were treated with $nSiO_2$ suspension during leaf development (BBCH = 16; six leaves unfolded), branching (BBCH = 22; two lateral shoots visible) and capitulum emergence stages (BBCH = 50; beginning of capitulum formation, still enclosed by leaves). Whole plants (stems and foliage) were all sprayed until solution started to drip onto the ground.

The ground cover was determined as the amount of dead plant material that covers the soil surface. The average canopy spread is the average horizontal width of the plant canopy, taken from right to left as one moves around the plant. Ground cover and canopy spread were measured during the flowering stage (BBCH = 65; 50% of florets open in flowers on

Table 1. Summarized metrological data of 2015 growing season for Maragheh station

	Minimum temperature (°C)	Maximum temperature (°C)	Mean temperature (°C)	Precipitation amount (mm)	Mean humidity (%)	Actual crop evapo-transpiration (mm)
March	1.9	13.5	8	12.69	49.7	45.51
April	6.1	19.4	13.6	25.9	41.8	68.10
May	11.4	25.5	19.5	11.14	36.7	89.56
June	17.7	32.7	263	2.87	23.9	115.36
July	22	36.4	29.9	0.35	24	131.05

main shoot). A portable chlorophyll meter (SPAD-502) was used to measure the amount of chlorophyll in the leaf, by transmitting light from light emitting diodes (LED) through a leaf at wavelengths of 650 and 940 nm. Chlorophyll content measurements were carried out ten times in upper fully expanded leaves at flowering stage.

At maturity stage, most of the leaves turned into a brown colour and very little green remained on the bracts of the latest flowering heads. Plants were harvested at ground level by hand from late June to early July. To determine the yield of achene and biological yield, plants were harvested from 2 m^2 after eliminating two side rows of each plot and 0.5 m from both ends of central rows. To study different agro-morphological traits, 10 plants were randomly selected in the field from each plot. The evaluated traits included the first capitulum height, the number of branches per plant, stem diameter (mm), capitulum diameter (mm), the number of capitula per plant, the number of achenes per capitulum, achene weight per capitulum, unfilled (empty) achene number per plant, thousand achenes weight. Plant height was measured from ground level to the tip of main stem at maturity time. The height of first branch was recorded from ground level to the first branching point on the main stem. Also the height of first capitulum was measured as the elevation of the nearest capitulum from ground level. Harvest index was calculated as the ratio of achene yield to aboveground dry matter at maturity. Data on agro-morphological traits were subjected to the analysis of variance (ANOVA) using the computer software SAS 9.1. The Duncan multiple range test at 5% level of probability was used to test significant main effects.

RESULTS

The analysis of variances revealed a highly significant effect of fertilizer treatment for most of the morpho-physiological traits, while nanoparticles affected only some traits (Table 2). The results showed that the effect of fertilizer and $nSiO_2$ on the height of first branch in plant and the height of first capitulum was not significant. However, Duncan's multiple comparison separated means of height of first capitulum between fertilizer treatments and application of 30 t ha^{-1} FYM (FYM1) was the only class significantly different between groups.

The investigation of canopy spread showed that both the fertilizer and $nSiO_2$ factors significantly affected this trait (with 95% confidence level). Comparison between the fertilizer treatments showed that the most widespread canopy was achieved by appli-

Table 2. Effect of fertilizer and nano-SiO_2 on some morpho-physiological traits of safflower

Fertilizers (F)	FBH	FCH	CS	SD	PH	CD	NUA	GC	CHL	CMB
Control	41.93 ± 3.61^{ab}	55.61 ± 8.85^{b}	25.53 ± 4.03^{b}	11.08 ± 1.81^{c}	67.78 ± 9.03^{c}	2.63 ± 0.42^{ab}	7.63 ± 2.38^{b}	55.50 ± 3.73^{d}	46.73 ± 5.27^{d}	2.56 ± 0.54^{b}
Chemical N-P-K	48.30 ± 3.25^{a}	62.15 ± 7.80^{b}	27.23 ± 6.03^{ab}	12.5 ± 1.41^{ab}	82.64 ± 11.26^{ab}	2.57 ± 0.26^{ab}	10.53 ± 2.87^{a}	70.83 ± 5.56^{c}	53.68 ± 3.44^{c}	2.65 ± 0.56^{ab}
FYM1	46.15 ± 5.12^{ab}	69.25 ± 2.99^{a}	35.07 ± 3.77^{a}	13.06 ± 4.10^{a}	87.58 ± 4.41^{a}	2.86 ± 0.09^{a}	8.46 ± 2.42^{b}	87.33 ± 5.61^{a}	63.67 ± 2.58^{a}	3.20 ± 0.52^{a}
FYM2	40.71 ± 6.32^{b}	56.70 ± 7.82^{b}	26.14 ± 6.79^{ab}	12.09 ± 1.57^{ab}	76.80 ± 7.51^{b}	2.46 ± 0.16^{b}	7.45 ± 2.87^{b}	79.00 ± 6.23^{b}	58.49 ± 2.49^{b}	2.73 ± 0.54^{ab}
Nano-SiO_2 (N)										
Non	44.54 ± 6.15^{a}	58.25 ± 9.41^{a}	26.25 ± 7.82^{b}	12.72 ± 1.16^{b}	75.96 ± 11.09^{b}	2.57 ± 0.29^{a}	8.74 ± 2.30 ^{a}	70.91 ± 12.60^{a}	54.24 ± 7.02^{a}	2.55 ± 0.52 ^{b}
With	44.00 ± 4.84^{a}	63.60 ± 7.40^{a}	30.78 ± 7.67^{a}	13.21 ± 5.28^{a}	81.44 ± 10.40^{a}	2.69 ± 0.28^{a}	8.30 ± 3.26^{a}	75.41 ± 13.55^{b}	57.03 ± 7.43^{a}	3.02 ± 0.52^{a}
Significance Level										
F	NS	NS	*	*	**	*	*	**	**	*
N	NS	NS	*	NS	*	NS	NS	*	NS	*
F×N	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
CV%	12.16	11.47	17.03	17.44	6.67	9.32	18.33	6.03	8.16	17.37

FBH – first branch height (cm); FSH – first capitulum height (cm); CS – canopy spread; SD – stem diameter (mm); PH – plant height (cm); CD – capitulum diameter; NUA – number of unfilled achene per plant; GC – ground cover (%); CHL – chlorophyll content (SPAD unit); CMB – number of capitula in main branch. Mean values of the same category followed by different letters are significant with 95% confidence level. FYM1: application of 30 t ha^{-1} farmyard manure; FYM2: application of 15 t ha^{-1} farmyard manure. In each cell the mean ± standard deviation is shown. F – Fertilizer; N – nano-silicon; N × S – interaction of fertilizer with nano-silicon; CV – coefficient of variation; NS – statistically non-significant; * – statistically significant with 95% confidence level and ** – statistically significant with 99% confidence level, respectively.

cation of 30 t ha^{-1} FYM, which was 37% higher than control. Furthermore, foliar application of $nSiO_2$ increased canopy spread up to 17% over the control. A similar trend was recorded for ground cover. Application of chemical fertilizer, FYM1 and FYM2, improved the ground cover up to 27%, 57% and 42% when compared to control, respectively. In addition, plants sprayed with $nSiO_2$ had a more expanded canopy compared to intact plants (Table 2). Also stem diameter responded to fertilizer treatment and application of 30 t ha^{-1} FYM increased stem diameter up to 19% over to control, while $nSiO_2$ did not significantly affect this trait (Table 2). Plant height was significantly affected by both factors and there was a significant (with 99% confidence level) fertlizer × $nSiO_2$ interaction effect (Table 2). The highest height was recorded in plants grown by application of chemical fertilizer along with $nSiO_2$ spray (91.60 cm), which followed by plant grown by application of 30 t ha^{-1} FYM along with nano-silicon spray. While the shortest plants were recorded under no fertilizer condition and without nanoparticle spray (62.44 cm).

Another important finding was the significant increase of chlorophyll content under the fertilizer treatment. The highest chlorophyll content was recorded for plants grown by application of 30 t ha^{-1} FYM (Table 2). Application of chemical N-P-K, 30 t ha^{-1} of FYM and 15 t ha^{-1} of FYM increased chlorophyll content over the control up to 15%, 36% and 25%, respectively.

Effect of different fertilizers and silicon dioxide nanoparticles on agro-morphological traits and yield components of safflower is shown in Table 3. Fertilizer treatments considerably affected the number of capitula in both main and secondary branches as well as the number of unfilled achene per plant. The comparison of mean number of capitula per plant showed that the application of chemical N-P-K, 15 t ha^{-1} of FYM and 30 t ha^{-1} of FYM increased this yield component over the control up to 28%, 55% and 11%, respectively (Table 3). Besides, foliar application of silicon dioxide nanoparticles increased the number of capitula in main branch up to 19% compared to intact plants (Table 2). It is somewhat surprising that the highest number of unfilled achenes was recorded in plant grown with chemical N-P-K fertilizer that was followed by FYM1 (Table 2). This partly may be due to significant increase of the number of achenes per both main and secondary capitula. So, the application of 30 t ha^{-1} FYM and chemical N-P-K increased the average number of achenes per capitulum by 47% and 22% compared to no fertilizer (Table 3).

Table 3. Effect of different fertilizers and silicon dioxide nanoparticles on agro-morphological traits and yield components of safflower

Fertilizers (F)	CSB	NCP	SMC	ASC	AAC	AWC	TAW	AY	STY	HI
Control	2.96 ± 0.92^{b}	5.53 ± 1.05^{b}	24.86 ± 4.3^{c}	29.30 ± 5.51^{b}	27.08 ± 4.08^{c}	0.66 ± 0.09^{c}	34.94 ± 0.54^{c}	1240 ± 70^{c}	3010 ± 231^{b}	36.77 ± 2.44^{ab}
Chemical N-P-K	4.46 ± 1.69^{ab}	7.11 ± 1.95^{ab}	34.46 ± 4.73^{b}	32.06 ± 3.12^{b}	33.26 ± 3.50^{b}	0.81 ± 0.05^{b}	35.80 ± 0.24^{b}	1442 ± 77^{b}	3190 ± 283^{b}	36.84 ± 1.92^{ab}
FYM1	5.43 ± 2.17^{a}	8.63 ± 2.35^{a}	42.66 ± 4.23^{a}	37.26 ± 6.02^{a}	39.96 ± 2.73^{a}	0.97 ± 0.07^{a}	36.45 ± 0.69^{a}	1843 ± 105^{a}	3789 ± 387^{a}	38.31 ± 2.77^{a}
FYM2	3.61 ± 0.94^{b}	6.35 ± 1.08^{b}	32.40 ± 7.52^{b}	27.83 ± 5.67^{b}	30.11 ± 6.38^{bc}	0.81 ± 0.05^{b}	35.84 ± 0.28^{b}	1451 ± 55^{b}	3827 ± 201^{a}	33.80 ± 1.40^{b}
Nano-SiO_2 (N)										
Non	3.87 ± 2.03^{a}	6.42 ± 2.32^{a}	31.11 ± 8.72^{b}	28.63 ± 6.07^{b}	29.87 ± 6.46^{b}	0.79 ± 0.11^{a}	35.65 ± 0.61^{a}	1472 ± 224^{a}	3429 ± 440^{a}	36.60 ± 3.08^{a}
With	4.36 ± 1.35^{a}	7.39 ± 1.49^{a}	36.08 ± 7.10^{a}	34.60 ± 4.62^{a}	35.34 ± 5.17^{a}	0.83 ± 0.14^{a}	35.87 ± 0.80^{a}	1516 ± 252^{a}	3474 ± 489^{a}	36.26 ± 2.25^{a}
Significance Level										
F	*	*	**	**	**	**	**	**	**	*
N	NS	NS	*	**	**	NS	NS	NS	NS	NS
F × N	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
CV%	20.84	19.57	12.35	17.44	6.67	8.26	1.09	15.66	6.35	5.99

CSB – number of capitula in secondary branch; NCP – number of capitula per plant; SMC – number of seed per main capitulum; ASC – number of achene per secondary capitulum; AAC – average number of achenes per capitulum; AY – achene yield (Kg ha^{-1}); STY – straw yield (Kg ha^{-1}); HI – harvest index (%); TAW – thousand achene weight (g); AWC – achene weight per capitulum. Mean values of the same category followed by different letters are significant with 95% confidence level. FYM1: application of 30 t ha^{-1} farmyard manure; FYM2: application of 15 t ha^{-1} farmyard manure. The mean ± standard deviations are shown. F – Fertilizer; N – nano-silicon; N × S – interaction of fertilizer with nano-silicon; CV – coefficient of variation; NS – statistically non-significant; * – statistically significant with 95% confidence level and ** – statistically significant with 99% confidence level, respectively.

A significant fertilizer × $nSiO_2$ interaction was recorded for achene number in main capitulum. Mean comparison revealed that the highest achene number in main capitulum was obtained from plant grown by application of 30 t ha^{-1} FYM and sprayed with $nSiO_2$, while the lowest amount was recoded for plants grown under no fertilizer condition without $nSiO_2$ foliar spray. Fertilizer application significantly increased the seed weight, so that the highest achene weight was recorded for plants grown with high FYM (30 t ha^{-1}). However, the application of chemical N-P-K or 15 t ha^{-1} FYM also increased this trait on average by 19%, compared to the control (Table 3).

Phenological growth stages of safflower under different fertilizer regimes and silicon dioxide nanoparticles spraying are presented in Table 4. Regular field monitoring during the growing season indicated that fertilizer application accelerated vegetative development and improved canopy spreading (Table 4). In fact, improvement of ground cover by application of fertilizers also reflects this point (Table 2). In contrast to earlier findings (Amanullah et al., 2011), no extension of phenological periods was detected by application of organic or inorganic fertilizers. On the other hand, foliar application of $nSiO_2$ under all fertilizer regimes, except high FYM (30 t ha^{-1}), accelerated plant growth and phenological development. Interestingly, $nSiO_2$ application under high FYM application condition enhanced duration of vegetative growth, days to flowering, capitulum formation compared to control plots. However, the effect on later phenological development was not considerable (Table 4).

The evaluation of achene yield, straw yield and harvest index also revealed that although the application of chemical N-P-K and 15 t ha^{-1} FYM slightly improved the harvest, the best status was obtained by application of 30 t ha^{-1} FYM (Table 3).

The correlations between different traits are presented in Table 5. Achene yield was observed to be significantly and positively correlated at 99% confidence level with ground cover, chlorophyll content, the number of capitula per plant, achene number in main capitulum, thousand achenes weight and seed weight per capitulum.

DISCUSSION

The present study demonstrated that the application of both organic and inorganic fertilizers significantly improved the growth characteristics of safflower as compared to the control. Rapid canopy closure is one of the very important characteristics of safflower in semiarid region with short growing sea-

Table 4. Phenological growth stages of safflower (*Carthamus tinctorius* L.) under different fertilizer regimes and silicon dioxide nanoparticles spraying according to the extended BBCH-scale

Fertilizer	N-SiO_2	30 DAS	40 DAS	50DAS	60 DAS	80 DAS	90 DAS
Control	non	32	39	50	59	79	83
	with	34	50	50	61	79	85
Chemical N-P-K	non	34	38	39	50	79	83
	with	38	39	50	61	81	89
FYM1	non	39	50	50	61	81	85
	with	38	39	39	55	79	83
FYM2	non	34	39	50	59	79	85
	with	39	39	50	61	79	89

DAS – days after seeding; 30+n – main stem elongation (n refers to number of the visibly extended internode in main stem); 50+n – capitulum emergence on main stem (50 – beginning of capitulum formation, still enclosed by leaves; 55 – capitulum clearly separated from the youngest foliage leaves; 59 – involucral bracts morphologically different: external, middle and internal bracts distinguishable); 60+n – flowering of main shoot (61– beginning of flowering: first florets open; 65–50% of florets open; 67–70% of florets open; 69–90% of florets open: end of flowering); 70+n – capitulum and fruit development (71 – capitulum begins to expand as fruits develop; 75 – capitulum reaches 50% of final size; 79 – capitulum and fruits reach final size: all florets withered and discoloured); 80+n – capitulum and fruit ripening (81 – involucral bracts are beginning to turn yellow; 83–30% of the capitulum area yellow; 85–50% of the capitulum area yellow; 87–70% of the capitulum area yellow: fruits reach physiological maturity; 89–90% or more of the capitulum area yellow: fruits fully ripe and ready for harvest). BBCH scale is described according to Flemmer et al. (2015). FYM1: application of 30 t ha^{-1} farmyard manure; FYM2: application of 15 t ha^{-1} farmyard manure.

Table 5. Pearson's correlation coefficients among agro-morphological traits of safflower

	FBH	FCH	CS	SD	GC	PH	CHL	CMB	CSB	NCP	AMC	ASC	AAC	MCD	SCD	TAW	AWC	NUA	AY	BY	STY
FCH	0.66*																				
CS	0.42	0.96**																			
SD	0.23	0.68*	0.73*																		
GC	0.25	0.66*	0.65*	0.60*																	
PH	0.60*	0.85**	0.77**	0.54*	0.72*																
CHL	0.25	0.69*	0.68*	0.60*	0.99**	0.73*															
CMB	0.25	0.74*	0.77**	0.87**	0.72*	0.53	0.75*														
CSB	0.73*	0.91**	0.79**	0.51	0.74*	0.89**	0.78**	0.64*													
NCP	0.65*	0.93**	0.85**	0.65*	0.79**	0.86**	0.83**	0.79**	0.98**												
AMC	0.57*	0.84**	0.75*	0.56*	0.84**	0.67*	0.86**	0.80**	0.88**	0.92**											
ASC	0.59*	0.86**	0.81**	0.77**	0.54*	0.58*	0.58*	0.90**	0.76*	0.86**	0.83**										
AAC	0.60*	0.88**	0.81**	0.67*	0.75*	0.66*	0.78**	0.88**	0.87**	0.94**	0.97**	0.94**									
MCD	0.43	0.85**	0.90**	0.58*	0.32	0.53	0.38	0.62*	0.67*	0.71*	0.59*	0.78**	0.70*								
SCD	0.07	0.11	0.12	0.15	-0.23	-0.13	-0.11	0.29	0.15	0.20	0.09	0.43	0.23	0.42							
TAW	0.40	0.72*	0.68	0.69*	0.95**	0.70*	0.92**	0.74*	0.74*	0.79**	0.86**	0.63*	0.80*	0.37	-0.29						
AWC	0.48	0.79**	0.73*	0.68*	0.95**	0.77*	0.95**	0.76**	0.87**	0.90**	0.91**	0.70*	0.86*	0.49	-0.08	0.96**					
NUA	0.86**	0.25	-0.03	-0.25	0.01	0.25	-0.01	-0.13	0.43	0.31	0.33	0.22	0.30	0.03	0.00	0.12	0.19				
AY	0.44	0.79**	0.75*	0.69*	0.90**	0.70*	0.92**	0.76**	0.85**	0.89*v	0.89**	0.72*	0.86*	0.59*	0.04	0.91**	0.98**	0.12			
BY	0.06	0.55*	0.58*	0.57	0.97**	0.59*	0.97**	0.68*	0.63*	0.69*	0.76**	0.45	0.66*	0.29	-0.18	0.89**	0.90**	-0.16	0.89**		
STY	-0.17	0.35	0.41	0.44	0.91**	0.46	0.90**	0.56*	0.44	0.50	0.59*	0.24	0.47	0.08	-0.30	0.78**	0.75*	-0.31	0.72	0.96**	
HI	0.63*	0.53*	0.44	0.38	0.03	0.15	0.05	0.29	0.43	0.42	0.39	0.59*	0.49	0.69*	0.38	0.22	0.32	0.40	0.43	0.00	-0.25

* Statistically significant with 95% confidence level and ** statistically significant with 99% confidence level, respectively. Abbreviations: FBH – first branch height; FSH – first capitulum height; CS – canopy spread; SD – stem diameter; GC – ground cover; PH – plant height; CHL – chlorophyll content; CMB – number of capitula in main branch; CSB – number of capitula in secondary branch; NCP – number of capitula per plant; AMC – number of achene per main capitulum; ASC – number of achene per secondary capitulum; AAC – average number of achenes per capitulum; MCD – diameter of main capitulum; SCD – diameter of secondary capitulum; TAW – thousand achenes weight; AWC – achene weight per capitulum; NUA – number of unfilled achene per plant; AY – achene yield; BY – biological yield; STY – straw yield; HI – harvest index.

son and it can significantly affect the yield potential. The rainfall regime in the Mediterranean semiarid areas is characterized by low, irregular and unpredictable precipitation, often concentrated in few months. The moisture supplied to the soil from rain is mostly lost by evaporation. Rapid canopy closure and a high percentage of ground cover under the Mediterranean conditions may provide numerous benefits. So that expanded canopy can improved the capturing (Soleimanzadeh & Gooshchi, 2012) and using solar radiation for photo assimilate synthesis throughout the rainy spring months. On the other hand, fast canopy closure can substantially reduce soil water losses through evaporation and it can lead to yield improvement. Another point worthy of attention is that safflower is a poor competitor with weeds, and fast canopy closure generally creates a more competitive stand of the established crop, which is important in water limited systems such as the arid and semiarid regions.

Our results about stem diameter further support the idea of Naderi & Ghadiri (2011), who showed that organic fertilizer (urban waste compost and manure) can improve stem diameter and leaf area of corn (*Zea mays*) compared to the control and chemical fertilizer. They also suggested that organic fertilizers are effective nutrient sources for crop production and it can be considered as potential alternatives to chemical N fertilizer.

Plant height significantly responded to fertilizer treatment, also similar results were reported by Hasan et al. (2013) and Naik et al. (2010), who found that both chemical and organic fertilizer applied to sunflower and safflower had significant influence on the plant height. Furthermore, application of $nSiO_2$ had a significant effect on plant height. These results are in contrast with the studies of Le et al. (2014), who reported the average plant height of cotton to decrease by $nSiO_2$. This suggested that the nanomaterials may have dissimilar effects on different plant species. Overall, the improvement of growth parameters by foliar application of $nSiO_2$ can be attributed to promotion of the some elements transport in xylem sap (Mg, Fe, and etc.), enhancement of uptake capacity of water and fertilizers, stimulation of the activity of some key enzymes such as nitrate reductase, increase of Indole-3-acetic acid (IAA) concentration and enhanced antioxidant activity (Lu et al., 2002; Le et al., 2014). Moreover, in the current study, $nSiO_2$ foliar application slightly altered the phonological pattern; however, this may be the result of changes in intracellular processes associated with growth. However, a detailed interpretation of these effects is necessary for the evaluation of cellular and molecular mechanisms.

The present observation of improved chlorophyll content with both organic and inorganic fertilizers is supported by the results of Bokhtiar & Sakurai (2005) and are in line with our earlier observations content in lentil leaves under semiarid highland conditions (Janmohammadi et al., 2014). As magnesium, nitrogen, sulphur, zinc, copper, iron and manganese are the soil nutrients that are directly or indirectly involved in chlorophyll biosynthesis (Marschner, 2012), hence one of improving effects of fertilizers on chlorophyll content of leaf tissues may be due to greater supply of the mentioned nutrients. However, constant increases of chlorophyll content may lead to an increase in photosynthesis (source strength) and ultimately lead to better status. However, in the current study the highest chlorophyll content and best plant growth were obtained by application of high FYM. Although it has been revealed that chlorophyll content increased in basil (*Ocimum basilicum*) leaves with application of silica nanoparticles (Kalteh et al., 2014), however, the observed difference between chlorophyll content of plant sprayed with $nSiO_2$ and intact plants in this study was not significant.

Our finding revealed that achene number per both main and secondary capitula considerably increased by FYM. Similarly, Hasan et al. (2013) showed a fruitful effect of FYM on the number of achenes per capitulum in sunflower, they also reported that the highest sterility percent was obtained by application of high FYM (30 t ha^{-1}).

Achene weight was significantly increased by fertilizer treatments. Achene filling in most crops depend on photo assimilates supplement from two resources: photosynthetic organs (current assimilates) and remobilization of stored resources wherein assimilates redistributed from reserve pools in vegetative tissues (Yang & Zhang, 2006). Increase of achene weight under fertilizer application can be attributed to the improved supply of photo assimilates resulting from the abundance of essential elements, which are utilized for enlargement of the sink cells (Dordas & Sioulas, 2008) or it can be due to increased assimilates translocation from vegetative tissues to the achenes (Xie et al., 2014).

The results showed that the highest number of unfilled achenes was recorded for plants grown with chemical N-P-K fertilizer. Although safflower is basically self-pollinated, bees or other insects are normally required for optimum fertilization and maximum yield (Pandey & Kumari, 2007). With regards to the low organic matter content of the soil, it seems that incorporation of organic in soil improved physicochemical properties of soil and thereby improves plant growth and achene yield. In support of this it has been suggested that manure would increase soil organic matter content, hydraulic conductivity, water holding capacity and extensively decreased bulk density (Shirani et al., 2002). Also application of FYM increased the organic carbon, total N and available P, K and S contents of soil (Bokhtiar & Sakurai, 2005). Also enhanced availability of nutrients can be due to improved soil structure and increased microbial activity. Our results showed that there was no significant difference between achene yield of plants grown with chemical fertilizer and low FYM (15 t ha^{-1}). This finding is in agreement with Naderi & Ghadiri (2011) findings. It can be concluded that FYM can be considered as potential alternatives to chemical fertilizers in semiarid region. These results also revealed that organic fertilizer can provide sufficient nutrient supply for crop growth and development. In line with the present result, SATYANARAYANA et al. (2002) reported that application of farmyard manure at 10 t ha^{-1} increased achene yield of rice by 25% compared to no farmyard manure control. Also, the present findings seem to be consistent with other research, which found that FYM improved the achene yield, straw yield and harvest index in safflower (MALLIGAWAD, 2010), wheat (ELDARDIRY et al., 2013), lentil (JANMOHAMMADI et al., 2014). Overall, the study clearly indicates that under rainfed farming system, acceptable yield of safflower can be obtained with 30 t ha^{-1} organic. Thus, farm yard manure should be considered as one of the inputs in semiarid regions because of its ability to sustain soil fertility. Organic matter not only increases the water holding capacity of the soil, but also increases the available water for plant growth (TADESSE et al., 2013), therefore, application of organic materials have potential of improving safflower yield in areas with limited moisture and also it can be a convenient alternative for fossil fuel based inorganic fertilizers.

One of the most interesting findings was significant positive correlation of chlorophyll content with most of the yield components, so that it can be introduced as suitable descriptor for evaluation of safflower growth and yield in semiarid region. This trend was somewhat observable for canopy spread and ground cover. This probably refers to the importance of fast development and rapid ground cover in these regions. Besides, the results of correlation analysis showed that there is interrelationship between developmental (ground cover, canopy speared, etc.) and yield components, and this can be important for active plant-breeding programmes. It is encouraging to compare this finding with that found by OMIDI et al. (2009), who by multivariate analysis found that the most important traits that contributed to the genetic divergence in order of importance were achene yield per plant, biomass, height, the number of branches, days to flowering and capitulum diameter. These agro-morphological traits can be used as a basic character for developing safflower growth and yield in semiarid highland region.

CONCLUSIONS

We studied whether foliar application of silicon dioxide nanoparticles and different fertilizer application can affect morphological traits, plant phenology, and yield components under semiarid conditions. Our findings demonstrated that application of nanoparticles improved canopy spread, ground cover, the number of capitula in main branch and accelerated canopy closure; however, it did not significantly affect the achene yield. The highest plant growth and achene yield were recorded in safflower plants that were fed with high amount of FYM (30 t ha^{-1}) and were sprayed with nano- SiO_2 solution. Furthermore, the obtained results demonstrated that application of low amount of FYM (15 t ha^{-1}) and commercial N-P-K fertilizers similarly enhanced safflower achene yield, therefore, it can be concluded that application of even low level of FYM may save costs by eliminating the demand for inorganic fertilizers. The study indicated that the application of high amount of FYM (30 t ha^{-1}) resulted in the improvement of most agro-morphological peculiarities and this suggests that there is a great benefit to farmers with sufficient livestock holdings. Safflower plants in semiarid region undergo terminal drought stress. The results of the current study also showed that foliar application of nano-SiO_2 can somewhat increase the efficiency of safflower production systems under unfavourable environmental conditions. However, for more detailed interpretation, there is a critical need to evaluate long-term effects of continuous application of FYM on soil mineralogical properties in highland areas. Also future researches can be designed for identifying the molecular mechanisms, by which nanoparticles exert their positive effect on plant growth.

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ANT LAPŲ PURŠKIAMO NANO SILICIO POVEIKIS DYGMINO AUGIMUI TRĘŠIANT ORGANINĖMIS IR NEORGANINĖMIS TRĄŠOMIS

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Santrauka

Silicio nanodalelės pasižymi savitomis fizikocheminėmis savybėmis – jos gali įsiskverbti į augalus, paveikti medžiagų apykaitą ir pagerinti augalų augimą bei derlių nepalankiose aplinkos sąlygose. Be to, mažas organinės medžiagos kiekis dirvožemyje, nesubalansuotos maistinės medžiagos ir nepakankamas vandens tiekimas gali turėti neigiamos įtakos pasėlių produktyvumui pusiau sausringose srityse. Norint suprasti per lapus purškiamo silicio dioksido nano dalelių ($nSiO_2$) poveikį mėšlu arba neorganinėmis trąšomis tręšiamo dygmino morfofiziologiniams požymiams ir derliui, eksperimentas buvo atliktas pusiau sausringame Maragheh aukštumos regione, Šiaurės Vakarų Irane. Eksperimentą sudarė du $nSiO_2$ lygiai (0 ir 20 mM) ir keturi tręšimo režimai (kontrolė, 15 t ha^{-1} mėšlo, 30 t ha^{-1} mėšlo, 90 kg ha^{-1} N-P-K cheminių trąšų). Augalai buvo veikiami $nSiO_2$ suspensija lapų vystymosi, šakojimosi ir graižo pasirodymo fazėse. Nors $nSiO_2$ žymiai pagerino kai kuriuos augimo parametrus (tokius kaip lajos plotis, stiebo skersmuo, augalų aukštis, grunto padengimas ir lukštavaisių skaičius graiže), bet neturėjo įtakos lukštavaisių derliui ir derliaus indeksui. Tačiau tręšimas ženkliai paveikė daugumą morfofiziologinių požymių, lukštavaisių derlių ir derliaus komponentus. Rezultatai parodė, kad geriausias augimas ir didžiausias lukštavaisių derlius buvo pasiektas prieš sėją tręšiant 30 t ha^{-1} mėšlo. Didelis mėšlo kiekis padidino lukštavaisių derlių 48 %, lyginant su kontrole, tačiau tręšiant N-P-K cheminėmis trąšomis ar 15 t ha^{-1} mėšlo lukštavaisių derlius padidėjo iki 17 %, lyginant su netręštais. Be to, šis darbas atskleidė teigiamą $nSiO_2$ egzogeninio taikymo poveikį dygminų augimui. Šie rezultatai rodo, kad tręšimas organinėmis trąšomis kartu lapus purškiant $nSiO_2$ gali pagerinti dygmino produkciją ir yra rekomenduotina agronominė priemonė.