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Article

Assessing the Potential of Polymer Coated Urea and Sulphur Fertilization on Growth, Physiology, Yield, Oil Contents and Nitrogen Use Efficiency of Sunflower Crop under Arid Environment

Sonia Perveen [1], Saeed Ahmad [2], Milan Skalicky [3], Ijaz Hussain [1], Muhammad Habibur-Rahman [2,4], Abdul Ghaffar [2], Muhammad Shafqat Bashir [5], Maria Batool [6], Montaser M. Hassan [7], Marian Brestic [3,8], Shah Fahad [9] and Ayman EL Sabagh [10,*]

1 College of Agriculture, Bahadur Sub Campus, Bahauddin Zakariya University, Layyah 31200, Pakistan; soniamustafa346@gmail.com (S.P.); ijazhussain546@gmail.com (I.H.)
2 Department of Agronomy, MNS-University of Agriculture Multan-Pakistan, Punjab 66000, Pakistan; saeedahmad.uam55@gmail.com (S.A.); mhabibur@uni-bonn.de (M.H.-R.); abdul.ghaffar@mnsuam.edu.pk (A.G.)
3 Department of Botany and Plant Physiology, Faculty of Agrobiology, Food, and Natural Resources, Czech University of Life Sciences Prague, Kamycka 129, 165 00 Prague, Czech Republic; skalicky@af.czu.cz (M.S.); marian.brestic@uniag.sk (M.B.)
4 Crop Science Group, Institute of Crop Science and Resource Conservation (INRES), University Bonn, 53115 Bonn, Germany
5 Department of Plant Breeding and Genetics, Ghazi University, Dera Ghazi Khan 32200, Pakistan; shafqatbashir02@gmail.com
6 College of Plant Science and Technology, Huazhong Agricultural University, Wuhan 430070, China; maria.batool@webmail.hzau.edu.cn
7 Department of Biology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia; m.sayd@tu.edu.sa
8 Department of Plant Physiology, Slovak University of Agriculture, Nitra, Tr. A. Hlinku 2, 949 01 Nitra, Slovakia
9 Department of Agronomy, The University of Haripur, Haripur 22620, Pakistan; shahfahad@uoswabi.edu.pk
10 Department of Agronomy, Faculty of Agriculture, Kafrelsheikh University, Kafr Elsheikh 33516, Egypt
* Correspondence: ayman.elsabagh@agr.kfs.edu.eg

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Abstract: Nitrogen and sulphur are fundamental macronutrients for the production of sunflower crop. Nitrogen is required consistently in larger amounts for sunflower production while common urea has more losses due to high solubility. On the other hand, sulphur application increases oil contents and availability of other essential nutrients (N, P, and K). Therefore, combined application of polymer coated urea with sulphur fertilization might be a promising option which can increase achene yield, oil contents, and nitrogen use efficiency (NUE). However, no particular studies have been conducted to explore the main and interactive effects of polymer coated urea and sulphur fertilization on growth, physiology, yield, oil contents, and NUE under arid field conditions. Hence, the current field experiment consisted of two nitrogen fertilizers [polymer coated urea (PCU) and common urea (CU)] and three sulphur fertilizer rates [S_0 (0), S_1 (30) and S_2 (60) kg ha^{-1})] in a split-plot arrangement under randomized complete block design (RCBD) during spring season of 2019 and 2020. Experimental results revealed that growth, physiology, yield, oil contents, and NUE of sunflower crop were significantly improved with the application of nitrogen fertilizers, sulphur fertilizer rates, and their interaction. Meanwhile, NUE, achene yield and oil contents were increased by 16.0–17.2%, 16.5–17.0%, and 2.96–3.19% respectively with the application of PCU compared with CU. Furthermore, NUE, achene yield and oil contents were also increased by 12.8–13.3%, 13.1–13.7%, and 10.7–10.9%, respectively, due to sulphur fertilization of 60 kg ha^{-1}compared with no sulphur application. Similarly, NUE, achene yield, and oil contents were increased by 32.9–39.5%, 31.7–32.6%, and 13.1–13.2% respectively with the application of PCU in combination with sulphur fertilization of 60 kg ha^{-1}compared with CU × S_0, which also evidenced a clear and positive interaction between nitrogen and sulphur. Conclusively, PCU (130 kg ha^{-1}) in combination with sulphur fertilization of 60 kg ha^{-1} is promising option for obtaining higher achene yield, oil contents, and NUE for sunflower crop under arid environment, and hence, it might be a good agronomic adaptation strategy for sustainable production of sunflower.

Keywords: plant height; total dry matter; yield attributes; net leaf photosynthetic rate; stomatal conductance; weather variability

1. Introduction

Sunflower is currently recognized a new emerging and fourth largest oilseed crop across the world [1]. Nitrogen is a primary and most consistently required plant nutrient in larger amounts than other plant nutrients for sunflower production [2,3]. Nitrogen initially helps in the speedy development of roots and leaves, production of chlorophyll content and ultimately enhances the biomass accumulation and yield attributes [4–6]. Common urea is usually used as a nitrogen (N) fertilizer applied at critical growth stages to meet the dynamic nitrogen demand of crops [7,8]. However, one fourth of the nitrogen applied through common urea is lost to environment in the form of denitrification, nitrate leaching, and ammonia volatilization due to the quick release of nitrogen from the common urea [9]. Thus, farmers have to apply an additional N dose which lead to less monetary returns. Furthermore, quick N release from common urea also harms the water, soil, and air quality through the contamination of ground water, dispersion of soil structure and greenhouse gases (GHGs) emission into the atmosphere, respectively. Similarly, common urea has high solubility in the water which provides nitrogen an open access to leach down and runoff, ultimately causing problems for aquatic life [10–13]. Some previous studies have shown 30–60% N losses from common urea ultimately leads to low NUE, crop growth, and yield [14,15]. Thus, it is compulsory to optimize nitrogen fertilizer inputs to meet the requirement of sunflower crop and to reduce environmental pollution. To cope this problem, controlled release urea fertilizers (polymer coated urea) have developed to increase NUE and sunflower achene yield and to reduce sunflower production cost and also making the environment safe [16]. Several studies have found that the application of controlled release fertilizer significantly enhances the growth, physiological, and yield attributes of field crops for instance cotton, sunflower and pakchoi by meeting the dynamic nitrogen demand throughout growing seasons [17–19].

Although, high yield potential sunflower hybrids with higher demand of nutrients have been developed, however the limitation is the lack of imbalanced nutrition application for sunflower crop [20,21]. Hence, oil contents into the sunflower seeds are very low due to imbalanced nutrition especially sulphur which has direct role in the production of oil containing amino acids, i.e., cystine, methionine, and cystein [22,23]. Sulphur is a fourth vital nutrient for crops especially oilseed production after nitrogen, phosphorus, and potassium [24,25]. Furthermore, it is involved in the activation of certain enzymes [26], synthesis of chlorophyll content, protein, and certain vitamins and carbohydrate metabolism in the plants [22,23,27]. Moreover, sulphur also increases the availability of some essential nutrients, i.e., nitrogen, phosphorus, potassium, and zinc due to synergistic effect [28,29]. Similarly, the efficiency of nitrogen, phosphorus, and potassium reduces due to deficiency of sulphur and ultimately reduced crop yield [30,31], which also indicates that healthy crop growth and development is impossible without the application of sulphur. Some researchers found that the application of sulphur promotes the growth, yield attributes, and oil contents of sunflower crop [32–35]. Moreover, several studies have reported that sulphur application enhances the availability of other plant essential nutrients, i.e., nitrogen, phosphorus, and potassium to sunflower plants and uptake of these nutrients by sunflower crop [36,37].

Although past studies showed the effects of nitrogen and sulphur fertilization on growth and yield attributes of sunflower individually, the interactive effect of polymer coated urea fertilizer and sulphur on NUE, growth, yield attributes, and oil contents is limited available. Thus, the objective of the present study was to explore the main and interactive effects of polymer coated urea and sulphur application on growth, physiology, yield attributes, oil contents, and NUE in sunflower production under arid field environmental conditions.

2. Materials and Methods

2.1. Site, Soil, and Climate Characteristics

The field experiment was conducted in spring season 2018 and 2019 at MNS-University of Agriculture, Multan (30°15 N, 71°53 E) South Punjab, Pakistan. The experimental site was in an arid climate under irrigated conditions. The soil was loam with a high pH (8.00), low soil total nitrogen (75.5 mg kg^{-1}), lower organic matter content (0.81%), low available phosphorus 12 mg kg^{-1}, low available potassium 220 mg kg^{-1}, and lower available sulphur 21.3 mg kg^{-1}. Meteorological data of studied area during experimental years collected from automatic weather station installed 400 m away from MNS-University of Agriculture, Multan, Pakistan, illustrated in Figure 1. The mean maximum temperature 36.9 °C (2018) in the month of April and 37.2 °C (2019) in the month of May and mean minimum temperature 8.80 °C (2018) and 7.97 °C (2019) in the month of February were recorded during the experimental period (Figure 1). Furthermore, highest number of sunshine hours was observed in May and the smallest number of sunshine hours was in February and the total rainfall occurred during both experimental periods (February–May) was 19.4 mm (2018) and 70.8 mm (2019).

2.2. Experimental Details

2.2.1. Experimental Design

A split-plot arrangement under randomized complete block design (RCBD) with three replications was used to get data for statistical analysis. The main plots were specified to nitrogen fertilizers [polymer coated urea (PCU) and common urea (CU), 46% N] and sulfur fertilizer [$CaSO_4 \cdot 2H_2O$, 18% S] were specified to the sub-plots. Each experimental unit (EU) measured 5.00 m × 18.0 m and EUs were separated by a band of 0.50 m.

2.2.2. Variety and Experimental Setup

Sunflower variety Hysun-33 characterized as high yield yielding, fertilizers responsive was sown on 2 February 2018 and 3 February 2019 with a seed rate of 15 kg ha^{-1}, a distance of 75 cm ridge to ridge followed by 20 cm seed to seed (plant to plant). Whole of phosphorus (90 kg ha^{-1}) using triple super phosphate fertilizer (46% P_2O_5), potassium (60 kg ha^{-1}) using murate of potash fertilizer (50% K_2O_5) [1], and sulphur fertilizer rates (0, 30 and 60 kg ha^{-1}) using gypsum (18% S) and basal dose (65 kg ha^{-1}) of PCU and CU were applied before sowing seeds. The remaining PCU and CU was divided into two equal splits which were applied at seedling and 50% buds formation stage. In total, five irrigations were applied to the sunflower crops through both canal irrigation system and diesel operated water-lifting pump. Weeds in the experimental units were controlled by both application of pre-emergence herbicide Pendimethilin 30% EC at 0.75 kg a.i. ha^{-1} at 2 days after sowing (DAS) followed by one manual weeding at 40 DAS.

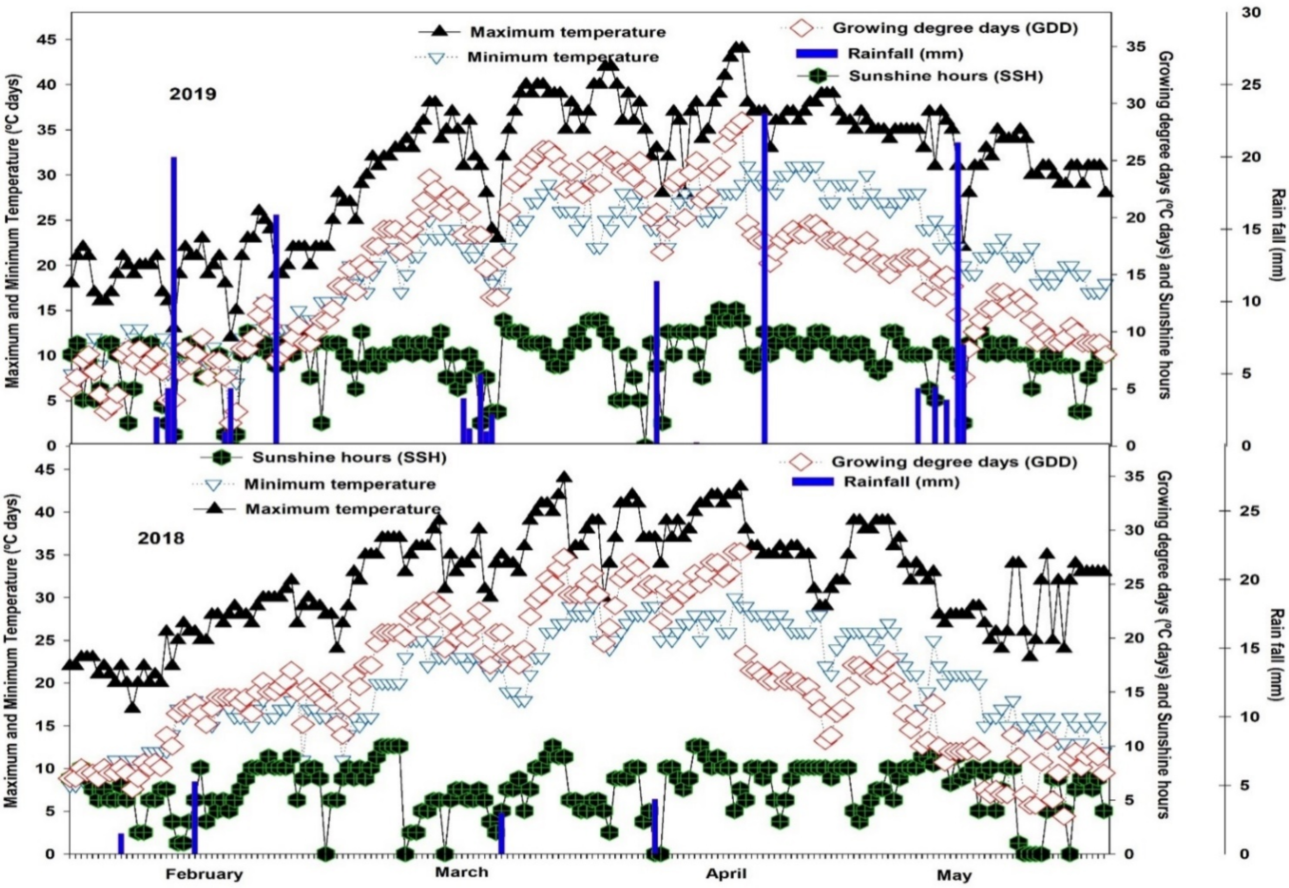

Figure 1. Daily weather variables (minimum, maximum temperature, rainfall, sunshine hours, and growing degree days during both experimental periods (2018 and 2019).

2.3. Measurements and Analytical Procedures

2.3.1. Growth Attributes of Sunflower Crop

Randomly ten plants from each experimental unit were tagged and numbers of leaves were counted, and mean number of leaves per plant was estimated. Plant heights (10 tagged plants) from base to tip of the plant's main stem with measuring tape was taken and mean plant height was estimated. At maturity, the sunflower plants were harvested from an area of 1 m^2 for calculation of total dry matter production (TDM). The harvested samples of plants were separated and oven dried at 65–70 °C until samples shown constant weight. Recorded dry weight of samples was converted into TDM (kg ha^{-1}).

2.3.2. Physiological Attributes

Chlorophyll content of tagged (10) plants at full canopy development stage (70 DAS) in each experimental unit was estimated by using a chlorophyll meter (SPAD-502; Minolta, Tokyo, Japan). Furthermore, net leaf photosynthesis rate and stomatal conductance of randomly tagged ten plants at full canopy development stage (70 DAS) in each experimental unit was estimated using CIRAS instrument. CIRAS stands for CubeSat infrared atmospheric sounder which is Portable Photosynthesis system developed by Dr. Keith J. Parkinson in 1984 when he was working at Rothamsted Experiment Station for the measurement of photosynthesis rate. Now, this instrument is widely used for the measurement of photosynthetic rate and stomatal conductance and other physiological attributes.

2.3.3. Yield Attributes and Oil Contents of Sunflower Crop

The sunflower crop was harvested on 27 May 2018 and 25 May 2019 and threshed at optimum moisture manually. Then, threshed achenes collected from each experimental unit were weighed using electric balance for the calculation of achene yield (kg ha^{-1}). For measuring 1000-achene weight, five samples of 1000-achenes separated achenes from each experimental unit were taken and their weight was determined on electric balance and their mean was calculated. For measuring achenes per head, numbers of achenes of five heads collected from each experimental unit were counted and their average was calculated. Sunflower achenes' oil contents were estimated by using Soxhlet apparatus [38]. In this technique, the proper amount of achenes was dried at 105 °C in an oven for about 8 h and grinded into a dry powdered material. Then, diethyl ether of low boiling point (40–60 °C) was utilized for extraction of fat from dry powdered material.

2.3.4. Estimation of Nitrogen Use Efficiency

Nitrogen use efficiency was estimated by using partial factor productivity and partial nutrient balance. Partial factor productivity (PFP) was measured by dividing the sunflower achene yield (kg) per kg of nitrogen applied [39,40].

$$\text{PFP (kg achene yield per kg N applied)} = \frac{\text{Achene yield (kg/ha)}}{\text{N applied (kg/ha)}}$$

2.3.5. Statistical Analysis

Recorded data comprising of growth, physiology, yield, achene oil contents and nitrogen use efficiency of sunflower was statistically analyzed by using analysis of variance (ANOVA) to determine the main and interactive effects of controlled release urea fertilizer and sulphur application on growth, physiology, yield, achene oil contents and NUE of sunflower crop under field conditions. Further, mean separation test (Tukey's Honest Significant Difference (HSD)) was used to distinguish differences between treatment means and were considered significant at $p \leq 0.05$ [41].

3. Results

3.1. Growth Attributes and Nitrogen Use Efficiency of Sunflower Crop

Number of leaves per plant, plant height (maturity), TDM and NUE were significantly (at $p \leq 0.05$) affected by the nitrogen fertilizers, sulphur fertilizer rates, and their interaction (Table 1). Sunflower crop fertilized with PCU showed significantly higher number of leaves per plant, plant height, TDM, and NUE as compared with common urea. Furthermore, growth attributes and NUE substantially increased with application of 30 and 60 kg ha^{-1} sulphur fertilizer rates than no sulphur fertilizer application. However, sunflower showed highest number of leaves per plant, plant height, TDM, and NUE with the sulphur fertilization of 60 kg ha^{-1} in comparison with 30 kg ha^{-1} and no sulphur fertilizer application. Furthermore, there was clear interaction between sulphur and nitrogen which resulted in higher growth attributes and NUE with the increasing level of sulphur fertilization. However, sunflower showed maximum number of leaves per plant, plant height, TDM, and NUE due to fertilization of PCU with 60 kg ha^{-1} S (Table 1).

Table 1. Main and interactive effects of polymer coated urea and sulphur fertilizer rates on the growth attributes and nitrogen use efficiency of sunflower crop.

Treatments	2018				2019			
	NLPP (No.)	PH (cm)	TDM (kg ha^{-1})	NUE (kg AY/kg N)	NLPP (No.)	PH (cm)	TDM (kg ha^{-1})	NUE (kg AY/kg N)
Nitrogen fertilizer (NF)								
CU	28.4 b	181 b	9243 b	16.9 b	32.3 b	183 b	9475 b	17.5 b
PCU	30.6 a	199 a	9437 a	19.8 a	33.3 a	201 a	9674 a	20.3 a
HSD at $p \leq 0.05$	1.23	4.67	175.9	0.459	0.490	0.507	182.4	0.417

Table 1. *Cont.*

Treatments	2018				2019			
	NLPP (No.)	PH (cm)	TDM (kg ha^{-1})	NUE (kg AY/kg N)	NLPP (No.)	PH (cm)	TDM (kg ha^{-1})	NUE (kg AY/kg N)
Sulphur fertilizer (SF)								
S_0	26.3 c	175 c	9084 c	17.3 c	31.3 c	176 c	9312 c	17.9 c
S_{30}	29.3 b	188 b	9265 b	17.9 b	32.6 b	190 b	9498 b	18.6 b
S_{60}	33.2 a	206 a	9672 a	19.6 a	34.6 a	209 a	9915	20.2 a
HSD at $p \leq 0.05$	2.32	3.78	151.4	0.124	0.408	0.475	156.1	0.108
CU × S_0	27.5 c	171 c	9058 c	16.1 e	31.1 c	171 f	9286 c	15.7 e
CU × S_{30}	28.4 c	176 c	9167 c	16.6 d	31.8 c	177 e	9398 c	17.2 d
CU × S_{60}	29.8 b	197 b	9504 ab	17.9 c	33.9 b	199 c	9742 ab	18.5 c
PCU × S_0	29.3 b	179 c	9110 c	18.5 c	31.4 c	181 d	9338 c	19.0 c
PCU × S_{30}	30.4 b	201 b	9362 bc	19.4 b	33.3 b	202 b	9599 b	19.9 b
PCU × S_{60}	33.2 a	215 a	9840 a	21.4 a	35.2 a	218 a	10088 a	21.9 a
HSD at $p \leq 0.05$	1.34	6.84	274.2	0.875	0.738	0.860	282.9	0.796
NF	**	**	*	**	**	**	*	**
SF	**	**	**	**	**	**	**	**
NF × SF	**	**	*	**	**	**	*	**

Means of main and interactive effects sharing same alphabet letter for a parameter did not differ significantly at $p \leq 0.05$; ** = Significant at $p \leq 0.01$; * = Significant at $p \leq 0.05$; NLPP = Number of leaves per plant; PH = Plant height (cm); TDM = Total dry matter (kg ha^{-1}); NUE = Nitrogen use efficiency (kg AY/kg N); CU = Common urea; PCU = Polymer coated urea; S_0= 0 kg ha^{-1}; S_1 = 30 kg ha^{-1}; S_2 = 60 kg ha^{-1}.

3.2. Physiological Attributes of Sunflower Crop

Chlorophyll content, net leaf photosynthetic rate (NLPR) and stomatal conductance (SC) were all considerably ($p \leq 0.05$) affected by the nitrogen fertilizers, sulphur fertilizer rates and interaction (Table 2). Sunflower crop fertilized with PCU produced significantly higher chlorophyll content, net NLPR and SC than common urea. Like growth attributes and NUE, physiological attributes of sunflower crop were substantially increased by application of 30 and 60 kg ha^{-1}sulphur fertilizer rates in comparison to no sulphur fertilizer application. However, sunflower showed highest chlorophyll content, net leaf photosynthetic rate, and stomatal conductance with the sulphur fertilization of 60 kg ha^{-1} in comparison to 30 kg ha^{-1} and no sulphur fertilizer application. Furthermore, there was also clear evident regarding interaction between sulphur and nitrogen because physiological attributes of sunflower crop considerably increased with the increasing levels of sulphur fertilization. However, sunflower crop showed chlorophyll content, net leaf photosynthetic rate and stomatal conductance with the application PCU in combination with sulphur fertilization of 60 kg ha^{-1} (Table 2).

Table 2. Main and interactive effects of polymer coated urea and sulphur fertilizer rates on the physiological attributes of sunflower crop.

Treatments	2018			2019		
	CH (Spad value)	NLPR (μmol m^{-2}s^{-1})	SC (mol m^{-2}s^{-1})	CH (Spad value)	NLPR (μmol m^{-2}s^{-1})	SC (mol m^{-2}s^{-1})
Nitrogen fertilizer (NF)						
CU	53.2 b	15.9 b	0.380 b	54.3 b	16.3 b	0.385 b
PCU	54.8 a	17.4 a	0.435 a	56.0 a	17.8 a	0.440 a
HSD at $p \leq 0.05$	0.048	0.047	0.0274	0.417	0.417	0.0286
Sulphur fertilizer (SF)						
S_0	52.8 a	15.3 c	0.325 c	53.9 c	15.7 c	0.330 c
S_{30}	53.7 b	16.5 b	0.420 b	54.9 b	16.9 b	0.425 b
S_{60}	55.4 a	18.1 a	0.478 a	56.7 a	18.5 a	0.483 a
HSD at $p \leq 0.05$	0.405	0.055	0.0126	0.388	0.348	0.0122
CU × S_0	52.3 d	14.9 f	0.307 c	53.4 d	15.3 c	0.312 c
CU × S_{30}	52.7 cd	15.4 e	0.366 b	53.7 cd	15.7 c	0.372 b
CU × S_{60}	54.6 b	17.3 c	0.466 a	55.7 b	17.7 b	0.472 a

Table 2. *Cont.*

Treatments	2018			2019		
	CH (Spad value)	NLPR (µmol $m^{-2}s^{-1}$)	SC (mol $m^{-2}s^{-1}$)	CH (Spad value)	NLPR (µmol $m^{-2}s^{-1}$)	SC (mol $m^{-2}s^{-1}$)
PCU × S_0	53.3 c	15.7 d	0.342 b	54.4 c	16.1 c	0.347 bc
PCU × S_{30}	54.9 b	17.6 b	0.473 a	56.2 b	18.1 b	0.478 a
PCU × S_{60}	56.2 a	18.9 a	0.489 a	57.5 a	19.4 a	0.495 a
HSD at $p \leq 0.05$	0.604	0.099	0.0228	0.703	0.631	0.0222
NF	**	**	**	**	**	**
SF	**	**	**	**	**	**
NF × SF	*	**	**	**	**	*

Means of main and interactive effects sharing same alphabet letter for a parameter did not differ significantly at $p \leq 0.05$; ** = Significant at $p \leq 0.01$; * = Significant at $p \leq 0.05$; CH = Chlorophyll content (Spad value); NLPR = Net leaf photosynthetic rate (µmol $m^{-2}s^{-1}$); SC = Stomatal conductance (mol $m^{-2}s^{-1}$); CU = Common urea; PCU = Polymer coated urea; S_0 = 0 kg ha^{-1}; S_1 = 30 kg ha^{-1}; S_2 = 60 kg $ha^{-1.}$

3.3. Yield Attributes and Oil Contents of Sunflower Crop

Number of achenes per head (NAPH), thousand-achenes weight (TAW), achene yield (AY) and oil contents were all significantly (at $p \leq 0.05$) affected by the nitrogen fertilizers, sulphur fertilizer rates, and their interaction (Table 3). Sunflower crop fertilized with PCU produced significantly higher NAPH, TAW, achene yield, and oil contents in comparison to common urea. Like growth and physiological attributes and NUE, yield attributes, and achene oil contents were also substantially improved with the application of 30 and 60 kg ha^{-1}sulphur fertilizer than no sulphur fertilizer application. However, sunflower showed highest NAPH, TAW, AY, and achene oil contents with the sulphur fertilization of 60 kg ha^{-1} in comparison to 30 kg ha^{-1} and no sulphur fertilizer application. Furthermore, yield attributes and achene oil contents significantly increased with the application of PCU with high rates of sulphur fertilization. However, sunflower crop showed high NAPH, TAW, AY, and achene oil contents with the application PCU in combination with sulphur fertilization of 60 kg ha^{-1} (Table 3).

Table 3. Main and interactive effects of polymer coated urea and sulphur fertilizer rates on the yield attributes and oil contents of sunflower crop.

Treatments	2018				2019			
	NAPH (No.)	TAW (g)	AY (kg ha^{-1})	OC (%)	NAPH (No.)	TAW (g)	AY (kg ha^{-1})	OC (%)
Nitrogen fertilizer (NF)								
CU	1338 b	52.6 b	2194 b	37.2 b	1339 b	53.6 b	2270 b	37.6 b
PCU	1495 a	55.1 a	2567 a	38.3 a	1493 a	56.0 a	2644 a	38.8 a
HSD at $p \leq 0.05$	72.42	1.90	58.7	0.623	75.07	1.77	52.98	0.426
Sulphur fertilizer (SF)								
S_0	1311 c	50.7 c	2248 c	35.9 c	1311 c	51.7 c	2324 c	36.4 c
S_{30}	1383 b	53.6 b	2239 b	37.5 b	1385 b	54.5 b	2418 b	37.8 b
S_{60}	1555 a	57.1 a	2555 a	39.8 a	1552 a	58.2 a	2629 a	40.3 a
HSD at $p \leq 0.05$	15.14	0.794	16.03	0.463	25.20	1.04	13.88	0.486
CU × S_0	1230 d	50.4 d	2097 e	35.8 c	1232 d	51.5 d	2172 e	36.3 c
CU × S_{30}	1288 c	52.3 bc	2159 d	36.6 c	1292 c	53.0 cd	2239 d	37.1 c
CU × S_{60}	1496 ab	55.1 b	2327 c	39.1 b	1492 ab	56.3 b	2398 c	39.5 b
PCU × S_0	1393 bc	51.1 cd	2400 c	36.1 c	1389 bc	51.9 d	2476 c	36.5 c
PCU × S_{30}	1478 b	55.2 b	2519 b	38.4 b	1480 b	56.0 bc	2597 b	38.7 b
PCU × S_{60}	1614 a	59.1 a	2782 a	40.5 a	1612 a	60.1 a	2860 a	41.1 a
HSD at $p \leq 0.05$	27.42	1.44	111.9	0.838	45.65	1.89	101.1	0.881
NF	**	*	**	**	**	*	**	**
SF	**	**	**	**	**	**	**	**
NF × SF	**	**	**	**	*	**	**	**

Means of main and interactive effects sharing same alphabet letter for a parameter did not differ significantly at $p \leq 0.05$; ** = Significant at $p \leq 0.01$; * = Significant at $p \leq 0.05$; NAPH = Number of achenes per head; TAW= 1000-achene weight (g); AY = Achene yield (kg ha^{-1}); OC = Oil contents (%); CU = Common urea; PCU = Polymer coated urea; S_0 = 0 kg ha^{-1}; S_1 = 30 kg ha^{-1}; S_2 = 60 kg ha^{-1}.

4. Discussion

The sunflower plants need macronutrients consistently and in higher amounts for the optimum growth and development which leads to higher yield and quality attributes. Nitrogen and sulphur are fundamental macronutrients required in larger amounts for the optimum growth and development of sunflower plants [3,34]. However, nitrogen is a highly mobile nutrient which rapidly lost through denitrification, nitrate leaching, and ammonia volatilization which leads to reduced NUE [42,43], dispersion of soil structure, groundwater pollution, toxicity for aquatic life, and greenhouse gases emission into the atmosphere [4–47]. On the other hand, sulphur is also fundamental nutrient for crops especially oilseed crops production [24,25]. It is involved in the increasing the availability of other essential plant nutrients, i.e., nitrogen, phosphorus, and potassium hence it enhances nutrients use efficiency especially nitrogen use efficiency [28–30]. In the current study, we explored the main and interactive effects of polymer coated urea fertilizer and sulphur application on growth, physiology, and yield attributes and oil contents of sunflower crop and NUE in sunflower production under arid field conditions.

In the current study, growth attributes (number of leaves per plant, plant height, and TDM) of sunflower crop and NUE were significantly increased by nitrogen fertilizers, sulphur fertilizer rates and their interaction. Sunflower crop showed higher growth attributes and NUE with the application of PCU and S_{30} and S_{60} in comparison to CU and S_0 might be associated to imperative role of nitrogen and sulphur in increasing the production of chlorophyll content, optimum rate of photosynthetic process, canopy production, net assimilation rate ultimately higher growth attributes [48,49], and sufficient uptake of nitrogen due to slowly release of nitrogen from PCU [34,37,50–52]. Furthermore, the effect of sulphur application was relevance when nitrogen was available in sufficient amounts which indicated a positive interaction between PCU and sulphur fertilization on growth attributes of sunflower and NUE as also observed in cotton [17–53]. Several other investigations have also examined improvement in the growth attributes of wheat and NUE with the application of PCU and positive interaction between nitrogen and sulphur [54,55].

Moreover, nitrogen and sulphur are also involved in the production of chlorophyll content which is a main constituent and directly involved in photosynthesis process and physiological attributes of plants [1,3]. In common urea, there is rapid hydrolyses process which lead to heavy nitrogen losses [56]. In the current study, physiological attributes (chlorophyll content, NLPR, and SC) of sunflower crop were significantly improved with the application of nitrogen fertilizers, sulphur fertilizer rates, and their interaction. Sunflower crop showed higher physiological attributes with the application of PCU and S_{30} and S_{60} in comparison to CU and S_0 might be because of the specific role in the activation of certain enzymes [26], synthesis of chlorophyll content and protein, and sufficient availability of nitrogen from PCU which corresponded well to the requirement of sunflower plants as similar findings reported by [17] in cotton production system. Furthermore, the interactive effect of PCU and sulphur application showed relevancy in physiological attributes because physiological attributes increased with increasing sulphur rate and PCU. Geng et al. [17] also reported improvement in the physiological attributes of cotton crop with the application of PCU and sulphur fertilization.

In the current study, yield attributes (NAPH, TAW and achene yield) were substantially increased by nitrogen fertilizers, sulphur fertilizer rates and their interaction. Sunflower crop produced higher number of achenes per head, 1000-achenes weight and achene yield with the application of PCU and S_{30} and S_{60} in comparison to CU and S_0 might be because of sufficient availability of nitrogen along with sulphur which accelerated photosynthetic process, leaf area production and net assimilation rate and ultimately yield attributes of crops [49,50,54,55]. Furthermore, higher yield attributes due to the interactive effect of sulphur application and PCU evidenced that there is highly positive interaction between sulphur and nitrogen [34] have studied and confirmed a positive interaction between nitrogen and sulphur in sunflower production. Moreover, sunflower crop showed higher oil contents with the application of PCU, S_{30}, and S_{60} in comparison to CU and

S_0 which might be because of fundamental function of sulphur in the production of oil containing amino acids i.e., cystine, methionine and cystein [22,23]. Despite the fact that higher nitrogen availability decreases the oil contents in sunflower production [56–59] interactive effect indicated that oil contents increased with the application of increasing sulphur rates with PCU in the current study. The results of our study are also similar with previous findings [34], presented that oil contents increases with the increasing sulphur and nitrogen fertilization in sunflower production.

5. Conclusions

In the present study, growth, physiology, yield attributes and achene oil contents of sunflower crop and NUE of sunflower crop were significantly improved with the application of nitrogen fertilizers, sulphur fertilizer rates and their interaction under field conditions. The highest growth, physiology, yield attributes and achene oil contents and NUE of sunflower crop was achieved with PCU (130 kg ha^{-1}) and S_{60} (60 kg ha^{-1} S) in comparison to CU (130 kg ha^{-1}) and S_0 (60 kg ha^{-1} S) under field conditions. In conclusion, PCU in combination with sulphur fertilization of 60 kg ha^{-1} would be recommended for achieving higher achene yield, achene oil contents and NUE of sunflower crop. Future studies are needed to explore the polymer coated urea and interactive effects of nitrogen and sulphur in improving the nutrients uptake, achene yield and NUE in sunflower production system under diverse environmental conditions. In future studies like the development of dynamic modeling solutions to explore the N and S dynamics from soil, root to plants under contrasting environment and assess these findings as adaptation under climate change scenarios for sustainable sunflower production.

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