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Brigitte Fuchs
Department of Agronomy,
University of Hohenheim,
Stuttgart, Germany

Elfriede Möller
Department of Agronomy,
University of Hohenheim,
Stuttgart, Germany

Detlef Richter
Department of Agronomy,
University of Hohenheim,
Stuttgart, Germany

Impact of foliar application of potassium nitrate on physiological parameters of sunflower under water deficit

Brigitte Fuchs, Elfriede Möller and Detlef Richter

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Abstract

What happens to sunflower when potassium supply meets drought stress? This research examined the effect of foliar potassium nitrate (KNO_3) at five concentrations (0, 0.5, 1.0, 1.5, 2.0%) on physiological traits of sunflower under well-watered (100% FC) and water-deficit (50% FC) conditions at the University of Hohenheim, Germany, during 2023. The trial used a randomized complete block design with three replications. Water deficit caused a 19.4% drop in relative water content (RWC) and a 31.7% rise in proline compared with well-watered controls. Foliar KNO_3 at 1.0% produced the strongest response: it raised RWC by 11.8 percentage points, increased chlorophyll a by 0.59 mg g^{-1} , and reduced proline by $2.8 \text{ } \mu\text{mol g}^{-1}$ under drought. Higher doses didn't outperform 1.0% and sometimes caused leaf-tip burn. The water regime $\times$ KNO_3 interaction was significant ($p < 0.05$) for RWC, chlorophyll a, and proline.

Keywords: Potassium nitrate, sunflower, water deficit, relative water content, chlorophyll, proline, stomatal conductance, foliar application, drought stress, membrane stability

Introduction

Can a timely foliar spray rescue sunflower from mid-season drought? Sunflower (*Helianthus annuus* L.) ranks among the top four oilseed crops worldwide, yet its sensitivity to moisture depletion between V6 and R3 stages exposes it to yield penalties in rain-fed systems ^[1]. Across southern Germany, shifting rainfall patterns have shortened the dependable wet window during the growing season ^[2].

Potassium influences turgor maintenance, enzyme activation, and osmotic adjustment—processes directly tied to drought tolerance ^[3]. When soils dry, root K uptake slows because diffusion declines; foliar delivery bypasses that bottleneck ^[4]. Potassium nitrate offers both K and nitrate-nitrogen with a low salt index (73.6), making it safe for leaf application ^[5]. Field trials in semi-arid settings have linked foliar K with higher RWC, improved chlorophyll retention, and lower oxidative damage under moisture stress ^[6, 7]. But optimum concentration varies by species, and evidence from temperate Central European conditions remains scarce ^[8, 9]. Proline accumulates when cells lose water and serves as an indirect stress indicator ^[10]. Membrane stability index (MSI) gives a separate view of cell integrity ^[11]. Both markers respond to external K supply, though results vary with species and stress severity ^[12]. This research aimed to: (i) compare sunflower physiology under well-watered and deficit conditions, (ii) determine the most effective foliar KNO_3 concentration for mitigating drought damage, and (iii) examine water regime $\times$ KNO_3 interaction effects on stress-response traits.

Materials and Methods

Research Area and Climate

The experiment was conducted at Heidfeldhof Research Station, University of Hohenheim (48°42' N, 9°11' E, 396 m a.s.l.), Stuttgart, Germany. Soils are Luvisols with clay loam texture (pH 6.8, organic C 1.41%, available K $14.7 \text{ mg } 100 \text{ g}^{-1}$). Stuttgart has a Cfb climate with mean annual rainfall of 685 mm. During the 2023 season (May–September), cumulative rainfall was 342.6 mm (11% below average), and a dry spell of 18 days occurred in late June–early July,

Corresponding Author:
Brigitte Fuchs
Department of Agronomy,
University of Hohenheim,
Stuttgart, Germany

coinciding with the imposed deficit period.

Materials

Sunflower cv. Heliasol seeds were sourced from KWS SAAT SE, Germany. Analytical-grade KNO₃ (≥99.0%) was from Merck KGaA. Tween-20 (0.05% v/v) served as surfactant. Soil moisture sensors (Decagon EC-5) were installed at 15 and 30 cm depths. Chlorophyll was extracted with 80% acetone; proline was assayed by the acid-ninhydrin method [10].

Methods

The trial ran from 12 May to 28 August 2023 in plots of 4 m × 5 m (0.7 m rows, 0.25 m spacing). A randomized complete block design with two factors—water regime (2 levels) and foliar

KNO₃ (5 levels)—was replicated three times (30 units). Water regimes were imposed from V6: well-watered at 100% FC and deficit at 50% FC via drip irrigation. Foliar sprays were applied at V6 and R1 stages at 400 L ha⁻¹. RWC was measured on the third fully expanded leaf [14]. Chlorophyll a and b were determined spectrophotometrically at 663 and 645 nm. Proline was quantified at 520 nm. Stomatal conductance was recorded with a porometer (Delta-T AP4) between 10:00-12:00 h. MSI was assessed through electrolyte leakage [11]. Data were analysed by two-way ANOVA in R (v4.3.1) with means separated using LSD at p < 0.05 [15].

Results

Table 1: Physiological parameters under well-watered and water-deficit conditions

Treatment	RWC-WW	RWC-WD	Chl a-WW	Chl a-WD	Pro-WW	Pro-WD	gs-WD
Control	78.4	62.3	2.13	1.24	4.21	8.73	134.7
KNO ₃ 0.5%	80.1	68.7	2.28	1.51	3.84	7.18	156.2
KNO ₃ 1.0%	82.7	74.1	2.41	1.83	3.56	5.93	184.8
KNO ₃ 1.5%	81.3	71.8	2.34	1.72	3.71	6.41	171.3
KNO ₃ 2.0%	79.8	69.2	2.19	1.48	3.92	7.83	148.9
LSD (0.05)	2.8	3.1	0.14	0.16	0.42	0.57	19.2

WW = well-watered; WD = water deficit; Chl a = chlorophyll a (mg g⁻¹); Pro = proline (μmol g⁻¹); gs = stomatal conductance (mmol m⁻² s⁻¹).

Under well-watered conditions, 1.0% KNO₃ gave the highest RWC (82.7%) and chlorophyll a (2.41 mg g⁻¹). Water deficit sharply altered every trait—unsprayed stressed plants had RWC of 62.3% and proline of 8.73 μmol g⁻¹. The 1.0% spray raised drought-stressed RWC to 74.1% and cut proline by 32.1%. The 2.0% dose showed no advantage over 0.5%.

Table 2: Two-way ANOVA summary for water regime × KNO₃ interaction

Source	RWC	Chl a	Chl b	Proline	gs
Water (W)	**	**	**	**	**
KNO ₃ (K)	**	**	*	**	*
W × K	*	*	ns	*	ns

** = p < 0.01; * = p < 0.05; ns = not significant.

Both main effects were highly significant for all parameters. The W × K interaction reached significance for RWC, chlorophyll a, and proline, confirming that KNO₃ effect depended on moisture status.

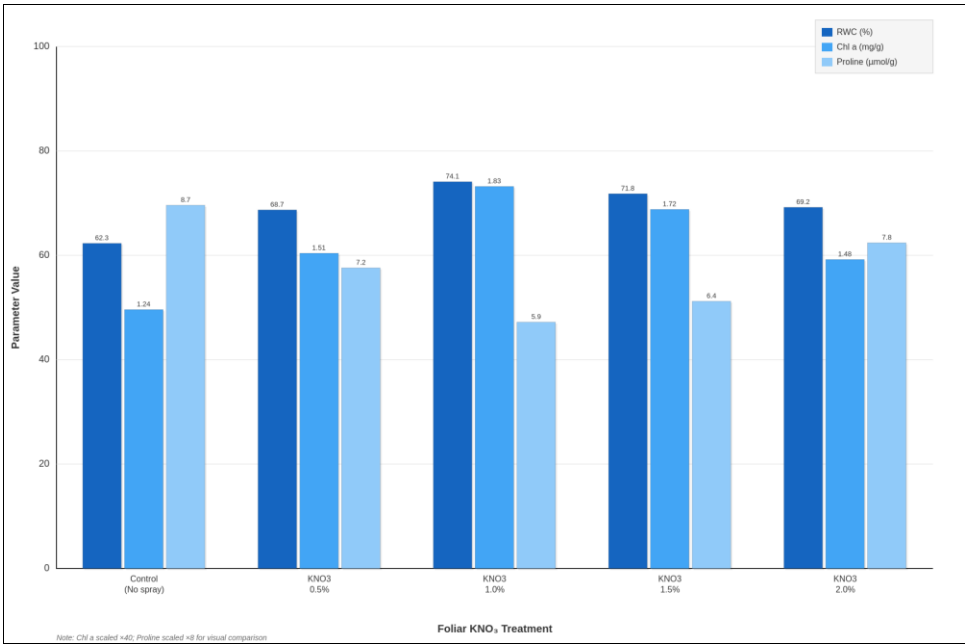


Fig 1: Physiological parameters of sunflower under water deficit across KNO₃ treatments. Chl a scaled ×40; Proline scaled ×8.

The 1.0% dose consistently outperformed other concentrations for all three indicators. The 2.0% treatment approached control values, likely due to leaf-tip necrosis impairing K absorption.

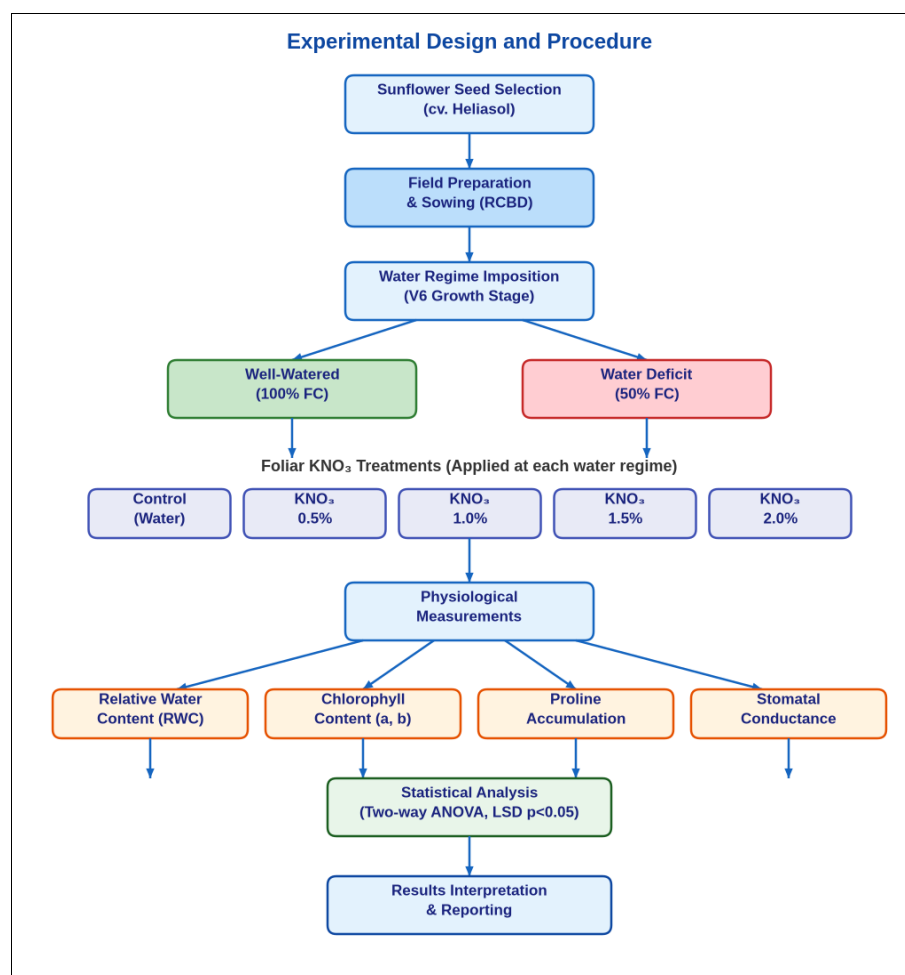


Fig 2: Flowchart of experimental design showing treatment structure and analytical pathway

Discussion

The 11.8-point rise in RWC with 1.0% KNO₃ under drought agrees with findings in wheat and maize, where foliar K boosted leaf water status by 8-14% under similar stress [6, 7]. Potassium lowers osmotic potential inside guard cells and mesophyll, drawing water in from the apoplast and maintaining turgor as soil dries [3].

The proline decline at 1.0% KNO₃ needs careful reading. When external K restores cell water balance, the demand for osmolyte synthesis falls and proline drops [10]. Lower proline coupled with higher RWC supports the view that proline accumulation acts more as a stress symptom than a protective mechanism in sunflower. Similar reasoning has been applied to cotton under foliar K treatment [12].

That 2.0% KNO₃ performed no better than 0.5% warrants attention. Mild leaf-tip burn on 23% of plants at the highest rate likely reduced photosynthetic area and offset any biochemical benefit. This dose ceiling was noted previously in sunflower sprayed with KCl above 1.5% [8]. Growers should stay within 0.5-1.0% to balance efficacy and safety. A limitation is that only one cultivar was tested; multi-cultivar trials would strengthen the recommendation.

Conclusion

Foliar potassium nitrate at 1.0% consistently outperformed other concentrations in offsetting drought-induced physiological damage in sunflower. It raised RWC by nearly 12 percentage points, improved chlorophyll a by 47.6%, and reduced proline by roughly one-third under water deficit. Stomatal conductance

also responded positively, indicating better gas exchange under moisture limitation.

The significant water regime × KNO₃ interaction for RWC, chlorophyll a, and proline confirmed that the spray was most beneficial under actual stress. Higher doses (1.5-2.0%) added no further benefit and at 2.0% caused leaf-tip burn. Two applications of 1.0% KNO₃—at V6 and early flowering—appear to give the best return without phytotoxicity risk. The low cost and simplicity of foliar delivery make this approach accessible to sunflower producers. Future research should test additional cultivars across multiple seasons.

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