



Exceeding Potassium and Zinc Application Rate above Farmers Practiced Rate Improves Dry Matter Partitioning, Photosynthetic Attributes, Yield and Quality of Maize (*Zea mays L.*) under Dryland Condition

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SB and VMB designed the study and wrote the experimental protocol. Authors PK and SK collected the field data while author BB recorded the photosynthesis parameters. Author DK performed the statistical analysis. Authors SB and PK also did the literature search. All authors read and approved the manuscript.

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ABSTRACT

Aims: This field experiment was conducted to compare the combined application of different rates of potassium and zinc application against the standard farmers practised application rate based on dry matter distribution, net photosynthesis, transpiration rate, sub stomatal CO₂ concentration, stomatal conductance, grain yield and quality attributes (protein and carbohydrate content and yield).

Place and Duration of Study: This short-term field trial was conducted on the Agronomy Research

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Farm of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India on the *Kharif* (Post monsoon) season of 2016.

Methodology: The experiment was conducted in Factorial Randomized Block Design (FRBD) with two factors i.e., potassium and zinc, each having three levels. The experiment was replicated thrice. The three potassium levels were 30, 60 and 90 kg K₂O ha⁻¹ while the zinc was applied 20, 30 and 40 kg ZnSO₄.7H₂O ha⁻¹ as three distinctive levels. A short duration dwarf maize cultivar Ravi-81 was used for the experiment.

Results: Perusal of experiment results confirmed that potassium and zinc have positive interaction even in short duration crop under dryland condition. The higher dry matter accumulation, crop growth rate, photosynthetic attributes, yield, protein content, protein yield, and carbohydrate yield has been recorded with the application of potassium at a rate of 60 kg K₂O ha⁻¹ along with zinc application of 30 kg ZnSO₄.7H₂O ha⁻¹ which has been found to be statistically superior over farmers adopted practice (30 kg K₂O ha⁻¹ along with zinc application of 20 kg ZnSO₄.7H₂O ha⁻¹).

Conclusion: Combined application of potassium and zinc has positive interaction on each other, and the increased rate is needed to meet the demand for short duration high yielding maize crop for enhanced growth, yield and quality attributes.

Keywords: Maize; potassium; zinc; interaction; photosynthesis; yield; protein.

ABBREVIATIONS

DAS : Days After Sowing,
K : Potassium
Zn : Zinc,
CGR : Crop Growth Rate,
CD : Critical Difference,
SEM : Standard Error of Means.

1. INTRODUCTION

Maize is currently one of the front leading cereal crops around the globe. The production of maize is increasing twice the annual rate of rice and three times of wheat [1]. A significant portion of maize growing area (64%) lies in developing countries, although only 43% of the world production is being harvested. However, the difference between the production from developing countries and developed countries is striking as productivity is 6.2 ton ha⁻¹ for developed countries while mere 2.5 ton ha⁻¹ in developing countries. The discrepancy of average yield level is a consequence of technological, environmental and organizational [2,3].

Within technological constraints; depletion of soil nutrient status due to continuous intensive cropping and less use of fertilizer inputs are the critical issue, especially in Asia and Africa [4]. India, one of the leading maize growing country, has a large portion of its maize area under dryland condition, which faces severe water and nutritional deficiency throughout the year [5,6]. Potassium and zinc are such nutrients often found to be deficient in dryland areas [7,8].

Maize is high potassium demanding crop which requires a steady supply of potassium throughout its growth period. Potassium, although it is a building block of organic matter in plants; it significantly influences plants physiology, growth, yield and quality attributes [9,10]. Potassium is responsible for activating more than 60 enzymes responsible for plant water balance, stomatal mechanism and photosynthesis-related attributes. As maize is known to over accumulate potassium even though only up to a certain point, potassium improves plant physiological attributes, it is necessary to pinpoint the threshold level of potassium to get the best physiological performance.

Another important aspect of consideration is that the interaction between potassium and other micronutrients especially zinc is not fully explored especially under actual field condition especially in dryland *vertisols* where potassium is supposed to be present on a higher level.

Zinc is particularly the element of interest as zinc deficiency is the most prevalent micronutrient deficiency globally. Just like potassium, maize (*Zea mays L.*) has a higher demand for zinc as compared to other crops, and zinc deficiency severely affects the maize production [11].

Knowledge of interaction between potassium and zinc on physiological functions, yield, and maize quality is essential to chalk out the best nutrient management strategies. In this short-term field experiment, we tried to evaluate potassium and zinc's effect on dry matter distribution Crop Growth Rate (CGR), photosynthesis-related

attributes during silking stage, grain yield, and protein and carbohydrate content and yield after harvesting stage.

2. MATERIALS AND METHODS

2.1 Experimental Setup

The field experiment was conducted during the post-monsoon season (sowing on 25th June and harvesting on 18th October) of 2016 in Akola district of Western Indian state of Maharashtra. The experimental plot (22.42° N latitude and 77.02° E longitude at an altitude of 307.42 m) belongs to Agronomy research farm of Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The soil type is categorized as Typic Haplusterts of *Vertisols* soil order and continuously cultivated for more than thirty years.

2.2 Physiochemical Properties of the Experimental Site

A physical and chemical analysis of soil (0-20 cm layer) further revealed that the soil belonged to clayey textural class (25% sand, 30% silt and 45% of clay) and had 201kg ha⁻¹ alkaline KMnO₄ oxidizable nitrogen [12], 15.79 kg ha⁻¹ available phosphorus [13], 367.30 kg ha⁻¹ 1 N neutral ammonium acetate exchangeable potassium [14], 0.59 mg kg⁻¹ DTPA extractable zinc [15] and 0.51% organic carbon [16]. The pH and the EC of the soil was 8.5 and 0.27 dsm⁻¹ respectively (1:2.5 soil: water ratio) [17,18].

2.3 Weather Condition during Experiment Period

According to the Köppen climate classification; the regions climate can be described as a tropical savanna climate with scorching summer and mild winter. The weather condition during the experiment duration has been presented on Table1.

2.4 Experimental Set-Up

Before the commencement of the experiment; the whole experimental site was ploughed with tractor-drawn moldboard plough followed by secondary tillage using Tyne cultivator and blade harrow to ensure fine tilting. Bund former was used to demarcate the bunds in the plots. Stubbles and weeds were collected and disposed of the field. Individual plots were levelled manually as per the layout plan one week before the sowing. The factorial Randomized Block Design (FRBD) was selected

as an experimental design with two factors: three levels and all the treatments were replicated thrice. The first factor was potassium(K) fertilization, and three levels were K₁-30 kg K₂O ha⁻¹, K₂-60 kg K₂O ha⁻¹ and K₃-90 kg K₂O ha⁻¹ respectively. In zinc (Zn); the constituent three levels were Zn₁- 20 kg ZnSO₄.7H₂O ha⁻¹, Zn₂- 30 kg ZnSO₄.7H₂O ha⁻¹ and Zn₃- 40 kg ZnSO₄.7H₂O ha⁻¹ respectively. The nine-treatment combination thus becomes: K₁Zn₁- (30 Kg K₂O+ 20 kg ZnSO₄.7H₂O) ha⁻¹, K₁Zn₂- (30 Kg K₂O+ 30 kg ZnSO₄.7H₂O) ha⁻¹, K₁Zn₃- (30 Kg K₂O+ 40 kg ZnSO₄.7H₂O) ha⁻¹, K₂Zn₁- (60 Kg K₂O+ 20 kg ZnSO₄.7H₂O) ha⁻¹, K₂Zn₂- (60 Kg K₂O+30 kg ZnSO₄.7H₂O) ha⁻¹, K₂Zn₃- (60 Kg K₂O+ 40 kg ZnSO₄.7H₂O) ha⁻¹, K₃Zn₁- (90 Kg K₂O+ 20 kg ZnSO₄.7H₂O) ha⁻¹, K₃Zn₂- (90 Kg K₂O+ 30kg ZnSO₄.7H₂O) ha⁻¹ and K₃Zn₃- (90Kg K₂O+ 40kg ZnSO₄.7H₂O) ha⁻¹.

The experiment does not have any formal control group (with 0 rates of application) as the base level of both potassium (30 kg K₂O ha⁻¹), and zinc (20 kg ZnSO₄.7H₂O ha⁻¹) is recommended dose of fertilizer for that area and acts as the control group. The net plot size was kept 24 m².

All the plots; irrespective of treatments were supplied with nitrogen at a rate of 120 kg N₂ ha⁻¹ and phosphorus at a rate of 60 kg P₂O₅ ha⁻¹ using graded fertilizer (20:20). The potassium source was murate of potash (60% K₂O) while zinc sulphate heptahydrate (21%Zn) was used as the source of zinc. The full dose of P and half dose of N was applied at the time of sowing while the remaining half of the nitrogen was top-dressed at 30 days after sowing. During the top dressing; urea was broadcasted near the crop rows. Potassium was also uniformly broadcasted to the plots as per the assigned treatments. The zinc was supposed to be applied as basal treatment; hence zinc sulphate was first dissolved in water and then sprayed near the crop rows for higher accessibility by the plants.

Sowing of maize variety Ravi- 81 was done with a seed rate of 20 kg ha⁻¹ and maintained a spacing of 60 x 20 cm. Seeds were dibbled at 3-5 cm depth at two seeds per hill. Thinning and gap-filling were done manually at ten days after sowing to maintain optimum plant population in the field. Gap filling was done by transplanting the extra seedlings available in the plots when the moisture content was at 100% saturation. Periodical hand weeding was done to keep the experimental plots completely weed-free. Irrigation (sprinkler) was given immediately after

completion of the sowing for better germination. Adequate moisture has been maintained in the plots; hence the plants did not experience any moisture stress.

2.5 Biometric Data Collection and Analysis

Periodical biometric observations were recorded at 20, 40, 60, 80 days after sowing and harvest stage. The dry matter distribution has been recorded from the above-ground biomass only; where all the different plant parts, i.e., leaf, stem and on later stages; cobs were kept in net bags and air-dried for few days followed by oven-dried at a constant temperature of 68 degree Celsius for 72 hours to get a constant dry weight.

Crop Growth Rate (CGR) was estimated using the formula proposed by Hunt (1978) at each 20 days interval. $CGR = (w_2 - w_1) / p \times (t_2 - t_1)$, where P= ground area, w_1 is the dry weight of plant recorded at time t_1 , w_2 is the dry weight of plant recorded at time t_2 , t_1 and t_2 were the interval of time, respectively and it is expressed in $gm^{-2}day^{-1}$.

Photosynthesis related attributes (Net photosynthesis, rate of transpiration, Substomatal CO₂ concentration and stomatal conductance) were measured for three constructive days during the silking stage in a full sunny day with a portable photosynthesis system, Infrared Gas Analyzer (LI-COR, LI-6400, Lincoln, NE, USA) from the middle portion of the third leaf, later the mean value of three days was statistically analyzed.

The protein content of maize grain was determined by the Folin – Lowry method by crushing the maize grain with a suitable buffer. After that, chemical analysis was done against standard prepared with BSA, and the reading was recorded in a spectrophotometer [19]. Starch content was determined by Anthrone's reagent method [20]. The protein and carbohydrate yield was measured by multiplying the respective protein and carbohydrate content by yield.

2.6 Statistical Analysis

All the experimental data were statistically analyzed using R statistical programme under R studio desktop environment (R studio, version 1.0.153). The Duncan Multiple Range Test (DMRT) was used for posthoc analysis and mean comparison. The graphs were prepared using Microsoft excel.

3. RESULTS AND DISCUSSION

A perusal of experiment data has revealed that application of potassium and zinc has significantly improved different attributes such as dry matter accumulation (g), photosynthetic attributes, grain yield ($q\ ha^{-1}$), protein content (%), protein yield ($kg\ ha^{-1}$) and carbohydrate yield ($kg\ ha^{-1}$).

3.1 Dry Matter Accumulation and Distribution in Different Plant Parts

The dry matter accumulation and distribution are the innate characteristics of the government by many factors such as cultivar and nutrient management [21,22]. The dry matter distribution in different plant parts at different growth stages has been presented in (Fig. 1). Analysis of variance showed a significant difference in dry matter accumulation among plants subjected to different potassium and zinc application rates in all growth stages except 20 DAS (Days after Sowing). At 40 DAS (days after sowing), K_2Zn_1 ($60\ kg\ K_2O\ ha^{-1}$ along with $20\ kg\ of\ ZnSO_4.7H_2O\ ha^{-1}$) recorded 14.75 g DM in leaves and 12.82 g DM in the stem which was 17.71% and 12.79% higher than K_1Zn_1 ($30\ kg\ K_2O\ ha^{-1}$ and $20\ kg\ of\ ZnSO_4.7H_2O\ ha^{-1}$). The leaf accumulated more dry matter than the stem which however inverted at succeeding growth stages.

On 60 DAS (Days After Sowing), K_2Zn_1 accumulated 25.48 g DM in leaves and 35.58g DM in the stem which was 13.98% and 11.41% higher than K_1Zn_1 . On 80 DAS (Days After Sowing), the trend had been changed as K_2Zn_2 ($30\ kg\ K_2O\ ha^{-1}$ and $20\ kg\ of\ ZnSO_4.7H_2O\ ha^{-1}$) recorded highest DM accumulation in leaves (21.39 g), stem (52.74 g) and cob (14.92 g) which were 19.33%, 22% and 19.41% higher than the K_1Zn_1 treatment combination. The trend also remained unchanged at the time of harvesting. The K_2Zn_2 reserved high dry matter in leaves (17.18 g), stem (70.01g) and in cob (118.65 g) which were outwardly 16.17% 18.56% and 18.11% higher than the DM accumulation in leaves, stems and cobs of K_1Zn_1 . The dry matter accumulation has increased over time irrespective of treatment however the accumulation was more in case of increased application rate of K and Zn at a rate of $60\ kg\ K_2O\ ha^{-1}$ along with $30\ kg\ ZnSO_4.7\ H_2O\ ha^{-1}$ than the farmers adopted practised of $30\ kg\ K_2O\ ha^{-1}$ along with $20\ kg\ ZnSO_4.7\ H_2O\ ha^{-1}$ although further increment of K and Zn application does not result in better DM accumulation.

The increase in DM accumulation maybe because K plays an essential role in plant enzymatic response, increase in metabolite concentration and protein synthesis [23,24]. On the other hand, zinc is also responsible for plant enzymatic activity, protein and carbohydrate metabolism, auxin regulation etc. which directly or indirectly influences dry matter accumulation in plant especially in reproductive phases [25]. In our experiment, potassium and zinc asserted positive interaction with each other in DM accumulation.

3.2 Crop Growth Rate (CGR)

Crop Growth Rate of the maize has been significantly improved due to the interaction of potassium and zinc application in all growth segments except 20- 40 DAS (Fig. 2). In 40-60 DAS, the highest CGR ($11.04 \text{ g m}^{-2} \text{ day}^{-1}$) has been recorded with the combination of K_2Zn_1 ($60 \text{ kg K}_2\text{O ha}^{-1} + 20 \text{ kg of ZnSO}_4 \text{ ha}^{-1}$) which was 17.86% higher than K_1Zn_1 ($30 \text{ kg K}_2\text{O ha}^{-1} + 20 \text{ kg of ZnSO}_4 \text{ ha}^{-1}$) while the second-highest CGR has been recorded with K_2Zn_2 ($60 \text{ kg K}_2\text{O ha}^{-1} + 30 \text{ kg of ZnSO}_4 \text{ ha}^{-1}$) which was 17.05% higher than K_1Zn_1 . On 60-80 DAS slab, the highest CGR ($16 \text{ g m}^{-2} \text{ day}^{-1}$) was recorded with K_2Zn_3 ($60 \text{ kg K}_2\text{O ha}^{-1} + 40 \text{ kg of ZnSO}_4 \text{ ha}^{-1}$) which was 15.92% higher than K_1Zn_1 . The K_2Zn_1 and K_2Zn_2 , which previously recorded higher CGR in 40-60 DAS have recorded 6.59% and 5.77% higher CGR than K_1Zn_1 .

On the final growth stage from 80 DAS to at harvest, the highest CGR ($27.79 \text{ gm}^{-2} \text{ day}^{-1}$) was recorded with K_2Zn_2 , which was 20.73% higher than K_1Zn_1 . An insight on CGR indicates that the performance of treatments on incremental growth was not uniform as on the initial period application of $60 \text{ kg K}_2\text{O ha}^{-1}$ along with 20 kg ZnSO_4 resulted in higher growth rate, however on later stages, although $60 \text{ kg K}_2\text{O ha}^{-1}$ remained best potassium application rate an increasing zinc application (30 and $40 \text{ kg ZnSO}_4 \text{ ha}^{-1}$) rate resulted in better crop growth in later stages.

Plant growth rate, i.e. accumulation of photosynthates over time mainly depends upon the photosynthetic functions such as maintaining the water balance in plant and regulating the stomata, which heavily depend upon potassium [26]. The zinc, on the other hand, significantly influences characters like intercellular CO_2

concentration, photosystem II and carbonic anhydrase activity which influences crop growth rate [27].

3.3 Photosynthetic Attributes

Interaction between K and Zn is statistically significant in the case of different photosynthetic attributes (Table 2). Compared to the treatment with the lowest application rate of K and Zn ($30 \text{ kg K}_2\text{O ha}^{-1}$ and $20 \text{ kg ZnSO}_4 \cdot 7\text{H}_2\text{O ha}^{-1}$); K_2Zn_2 (application of K at a rate of $60 \text{ kg K}_2\text{O ha}^{-1}$ and Zn at a rate of $30 \text{ kg ZnSO}_4 \cdot 7 \text{ H}_2\text{O ha}^{-1}$) has significantly increased the net photosynthetic rate (1P_n) by 53.67%. Neither the higher nor, the lower rate of application of both K and Zn resulted in the superior result; instead, the best result has been observed in the medium level of K and Zn. The trend remains the same in case of the rate of transpiration (2E), where K_2Zn_2 resulted in 34.64% higher values than the K_1Zn_1 . Interestingly, K_2Zn_2 also recorded a 16.92% higher transpiration rate than K_3Zn_3 , apparently having a higher application rate of potassium and zinc.

The highest substomatal CO_2 concentration (3g_s) has been recorded with K_2Zn_1 , which has been 70.77% higher than K_1Zn_1 but found to be statistically at par with K_2Zn_2 which recorded 64.52% higher substomatal CO_2 over K_1Zn_1 .

The treatment of K_2Zn_2 also recorded higher stomatal conductance which was 50% higher than K_1Zn_1 . K_2Zn_3 , which was statistically at par with K_2Zn_2 , recorded 49.68% higher stomatal conductance than K_1Zn_1 .

Leaf photosynthesis comprises of several physiological functions such as sunlight harvesting, phytochemistry of PSII and CO_2 assimilation. Potassium and zinc are essential nutrients which regulate these parameters and absence of both these nutrients reduces photosynthetic activity. Under potassium deficit condition, leaf net photosynthetic rate, stomatal conductance, photosynthetic phosphorylation activity and electron transfer energy is reduced in rice has earlier been reported by [28]. Similarly, zinc is also essential for different photosynthesis process as it helps in better assimilation of photosynthates. Comparable results also earlier been reported by [29].

3.4 Grain Yield

There are several factors which directly and indirectly influences the grain yield of maize and nutrient management is one of them. The increase in grain yield results from increased grain cob⁻¹, a higher number of grain rows, cob length, and cob diameter parameter. Our experiment's increased application rate of K and Zn and their interaction has resulted in higher grain yield than the farmer adopted practice (K₁Zn₁). Application of 60 kg K₂O ha⁻¹ and 30 kg of ZnSO₄.7H₂O recorded the highest grain yield in maize (4708 kg ha⁻¹), which was 36.64% higher than the K₁Zn₁ (Table 3). K₂Zn₁ recorded the second-highest grain yield, 4250 kg ha⁻¹ recorded 26.67% higher grain yield than K₁Zn₁. The increase in grain yield does not have a linear relationship with an increased application rate of K and Zn as increased application rate increased the grain yield up to a certain level and then declined. The increment of yield due to the stand-alone application of potassium and zinc on maize was also reported [30,31,32].

3.5 Protein Content and Protein Yield

Increased potassium and zinc application have resulted in increased protein concentration than the basic limit of farmers' adopted practice; however, except K₁Zn₁, all other treatments have similar grain protein concentration levels. The highest grain protein concentration (13.67%) was recorded in K₂Zn₂, 23.73% higher than K₁Zn₁ (Fig. 3). Protein yield (kg ha⁻¹) is the result of both protein content and grain yield. As the K₂Zn₂ treatment combination has significantly improved both the grain yield and protein content; the protein yield has also been improved (Table 3). The highest protein yield of 637.08 kg ha⁻¹ has been recorded with K₂Zn₂, 48.89% higher than the necessary K₁Zn₁ treatment combination.

The impact of abundant potassium application on an increased protein level is due to the enhanced activity of nitrate reductase enzyme, absence of which even higher level of nitrate does not results higher level of protein [33].

3.6 Carbohydrate Content and Carbohydrate Yield

Carbohydrate yield of maize does not change up to statistically significant level due to different doses of potassium, and zinc application as both standalone and interaction effect of K and Zn found non-significant (Fig. 3). Carbohydrate yield, however, has been significantly improved due to the fact that yield has been improved. The K₂Zn₂ recorded the highest carbohydrate yield of 2880.67 kg ha⁻¹, which was 29.18% higher than K₁Zn₁. K₂Zn₁ recorded carbohydrate yield of 2650.32 kg ha⁻¹, which was statistically at par with K₂Zn₂ recorded 31.12% higher carbohydrate yield than K₁Zn₁ (Table 3). Maize generally contains around 60% carbohydrate, mostly in the form of starch. It was observed that carbohydrate content in grain did not show any significant variation due to potassium and zinc nutrition management practices.

The reason can be argued that carbohydrate content is a genetic property that is not much affected by the external application of nutrients. The specific reason behind the failure of potassium to impart any effect of potassium is due to reduction of space availability for amyloplasts which finally limits the starch accumulation due to the size constraints of polygonal structured starch which can be seen in maize, rice and other cereal crops [34]. However, the carbohydrate yield (kg ha⁻¹) was increased with potassium and zinc nutrition because of the increased yield factor.

Table 1. Meteorological observations during study period

Month	Temperature (°C)		Relative humidity (%)		Total rainfall (mm)	Total evaporation (mm)
	Mean Maximum	Mean Minimum	Mean Maximum	Mean Minimum		
20-30 June	35.4	26.1	72.66	44.33	139.7	28.1
1-31 July	30.58	24.3	87.2	69.6	376.1	20.7
1-31 August	30.54	23.84	84.25	62.5	30.7	17.5
1- 30 September	31.34	23.4	88.4	61.8	123.2	18.2
1- 20 October	31.1	20.2	87.46	53.63	90.5	11.7

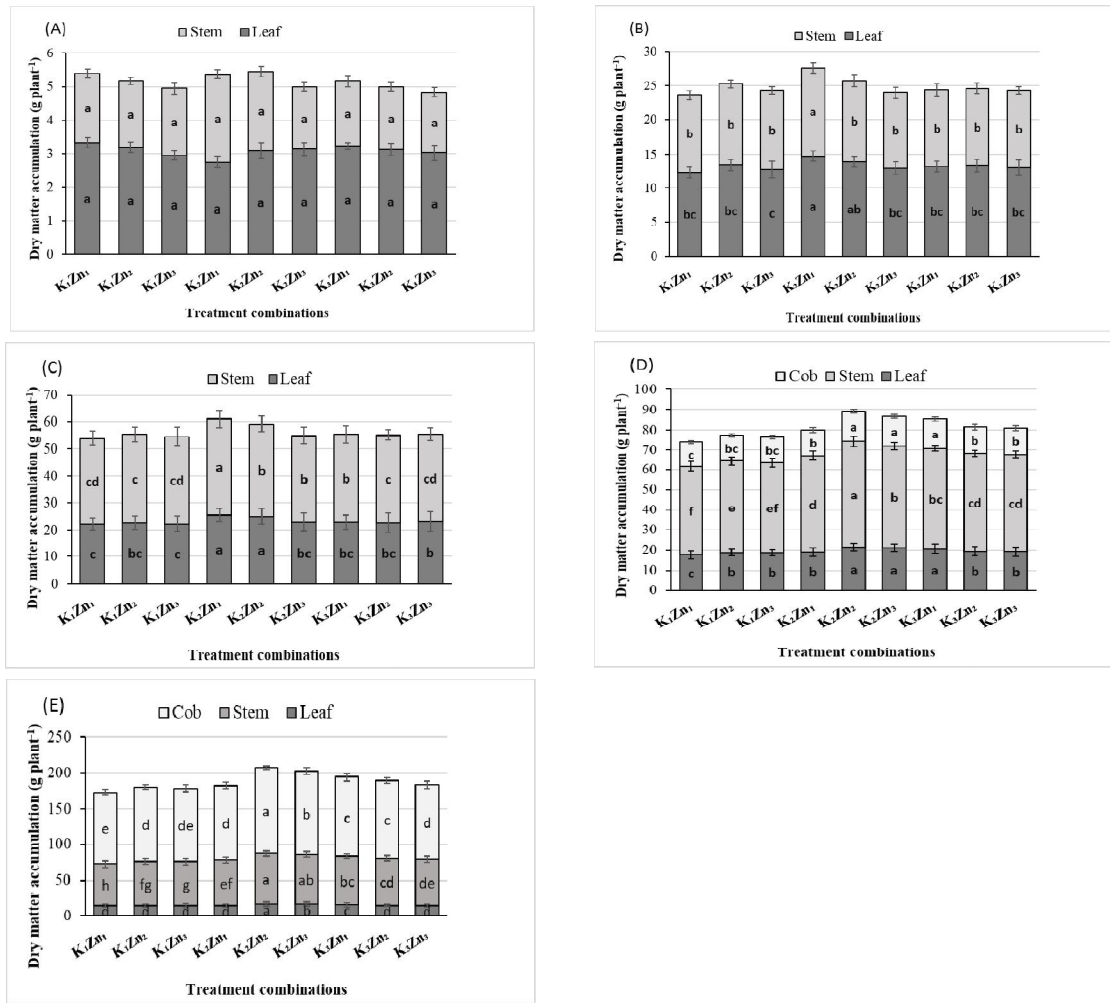


Fig. 1. Effect of different rates of potassium and zinc application rates on accumulated dry matter distribution at different plant parts of short duration maize at 20 (A), 40 (B), 60 (C), 80 (D) and final at harvest (E) stages. The vertical error bar indicates standard error of mean (n=3) values. Column segments sharing a common letter indicates both are statistically at par according to Duncan Multiple Range Test (P= 0.05)

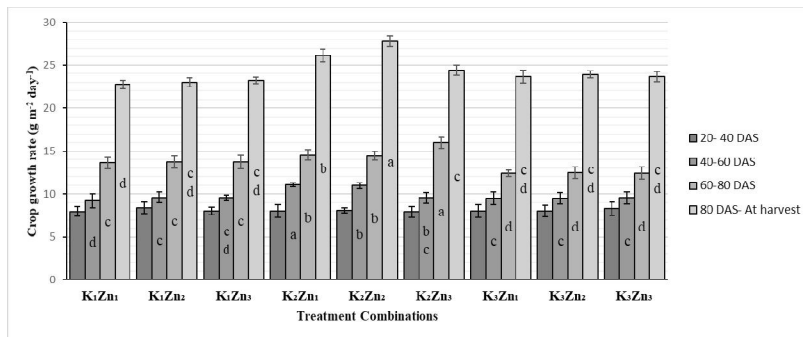


Fig. 2. Effect of different rates of potassium and zinc application rates on Crop Growth Rate (CGR) of maize at different stages of plant growth. The vertical error bar indicates standard error of mean (n=3) values. Column sharing a common letter indicates both are statistically at par according to Duncan Multiple Range Test (P= 0.05)

Table 2. Effect of different rates of potassium and zinc application rates on net photosynthesis, transpiration, substomatal CO₂ concentration and stomatal conductance during the silking stage of maize

Treatment combinations	¹ Pn(μmol/m ² s)	² E(mmol/m ² s)	³ g _s (mmol/m ² s)	⁴ Ci (mmol/m ² s)
K ₁ Zn ₁	7.88± 1.02 ^g	2.53± 0.43 ^f	0.21±0.01 ^d	89.48±15.24 ^f
K ₁ Zn ₂	9.36±0.86 ^f	2.83±0.19 ^e	0.24±0.03 ^d	114.48±12.19 ^d
K ₁ Zn ₃	9.30±0.79 ^f	2.78±0.22 ^e	0.23±0.01 ^d	107.17±10.50 ^e
K ₂ Zn ₁	10.02±0.93 ^e	2.94±0.43 ^d	0.44±0.02 ^a	117.44±12.31 ^{cd}
K ₂ Zn ₂	13.66±0.77 ^a	3.59±0.45 ^a	0.41±0.03 ^a	149.13±9.03 ^a
K ₂ Zn ₃	13.01±0.68 ^b	3.43±0.31 ^b	0.38±0.02 ^b	148.63±8.43 ^a
K ₃ Zn ₁	12.72±0.71 ^b	3.42±0.27 ^b	0.38±0.03 ^b	128.26±11.16 ^b
K ₃ Zn ₂	11.35±0.63 ^c	3.18±0.52 ^c	0.35±0.03 ^{bc}	125.71± 9.80 ^b
K ₃ Zn ₃	10.73±0.57 ^d	3.03±0.42 ^d	0.32±0.03 ^c	121.08±10.93 ^c
SEm ±	0.17	0.03	0.01	1.45
CD at 5%	0.49	0.09	0.04	4.36

(¹Pn-Net photosynthesis, ²E= Rate of transpiration, ³g_s= Substomatal CO₂ concentration, ⁴Ci= Stomatal conductance. Sharing a common letter indicates both are statistically at par according to Duncan Multiple Range Test (P= 0.05)

Table 3. Effect of different rates of potassium and zinc application rates on grain yield (kg ha⁻¹), protein yield (kg ha⁻¹) and carbohydrate yield (kg ha⁻¹) at final harvesting stage

Treatment combinations	Grain yield (kg ha ⁻¹)	Protein yield (kg ha ⁻¹)	Carbohydrate yield (kg ha ⁻¹)
K ₁ Zn ₁	3250 ±237 ^f	386.8 ±18.92 ^f	1936.66± 87.23 ^b
K ₁ Zn ₂	3583 ±311 ^{de}	428.50 ± 21.25 ^{ef}	2050.94 ± 101.32 ^b
K ₁ Zn ₃	4001 ±368 ^c	526.38± 31.12 ^{bc}	2252.55 ± 84.23 ^b
K ₂ Zn ₁	4250 ± 276 ^b	580.62 ± 16.93 ^{ab}	2650.32 ± 91.95 ^a
K ₂ Zn ₂	4708 ±385 ^a	637.08 ±34.76 ^a	2880.27 ± 86.92 ^a
K ₂ Zn ₃	3668 ±399 ^{de}	484.95 ± 25.07 ^{cde}	2227.71 ± 45.65 ^b
K ₃ Zn ₁	3505 ±304 ^e	459.46 ± 37.34 ^{de}	2076.41 ± 65.43 ^b
K ₃ Zn ₂	3750.2 ±433 ^d	510.03± 31.43 ^{cd}	2146.54 ±47.36 ^b
K ₃ Zn ₃	3501 ±452 ^e	462.07 ± 32.32 ^{de}	1964.21 ± 64.26 ^b
SEm ±	61.61	18.20	140.40
CD at 5%	184.71	54.56	420.89

(Sharing a common letter indicates both are statistically at par according to Duncan Multiple Range Test (P= 0.05)

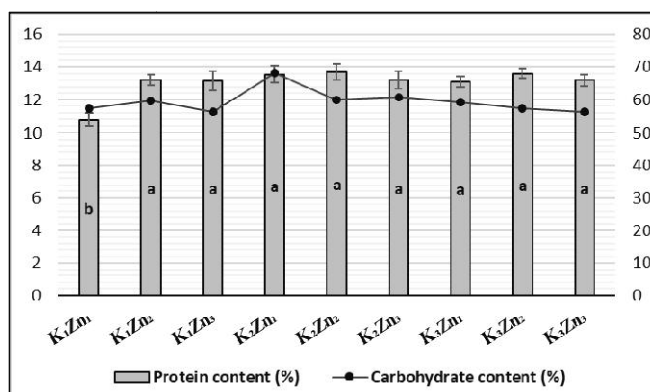


Fig. 3. Effect of different rates of potassium and zinc application rates on protein and carbohydrate content (%) of maize. The effect of potassium and zinc on carbohydrate content has been found to be statistically non-significant. The vertical error bar indicates standard error of mean (n=3) values. Column segments sharing a common letter (for protein contents only) indicates both are statistically at par according to Duncan Multiple Range Test (P= 0.05)

4. CONCLUSION

Potassium and zinc have significantly improved the dry matter accumulation in different plant parts, crop growth rate, photosynthetic attributes, grain yield, protein content, protein yield and carbohydrate in short duration maize under dryland condition when both were applied above farmers practised level of fertilization. The best result has been recorded with 60 kg K₂O ha⁻¹ along with 30 kg ZnSO₄.7H₂O ha⁻¹. Potassium and zinc also exhibit interaction effects even in short duration trial.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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