



# Impact of Different Potassium Levels on the Physicochemical Characteristics and Nutrient Content of Soil Cultivated with Safflower in Vertisols

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## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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## ABSTRACT

The present field experiment was undertaken at department field of soil science and agricultural chemistry, Vasantrya Naik Marathwada Krishi Vidyapeeth, Parbhani to assess the "Effect of Various Levels of Potassium on K-Adsorption and Release Behaviour under Safflower in Vertisol" during Rabi season of 2022-23 and 2023-24. Ten different treatments combinations were used in the experiment which includes different potassium rates and recommended dose of fertilizer and control replicated there in RBD (Randomized Block Design). The results emerged out indicated that the

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Bulk density, particle density, porosity, pH, EC and CaCO<sub>3</sub> was found non-significant at flowering and after harvest of safflower. Significantly higher value, of available N, P<sub>2</sub>O<sub>5</sub>, K, sulphur and DTPA Fe, Mn, Zn and Cu was recorded at flowering and after harvest of safflower in treatment receiving 100% RDF + 90 Kg K<sub>2</sub>O ha<sup>-1</sup> at par with the 100% RDF + 75 Kg K<sub>2</sub>O ha<sup>-1</sup>, 100% RDF + 60 Kg K<sub>2</sub>O ha<sup>-1</sup> and 100% RDF + 50 Kg K<sub>2</sub>O ha<sup>-1</sup> as soil is deficient in Zn and Fe. The alone results indicated that the potassium supplying capacity of soil is not only depend on available K in Vertisol but it's depend on the K fixation and release behaviour at added K in soil. The optimum K release and cost benefit ratio was recorded at application of RDF (60:40:00 Kg N and P<sub>2</sub>O<sub>5</sub>) + 50 kg K<sub>2</sub>O ha<sup>-1</sup>. This clearly indicated the application of 50 Kg K<sub>2</sub>O with RDF (60:40:00 Kg N and P<sub>2</sub>O<sub>5</sub>) was found beneficial than alone RDF for safflower in Vertisol.

**Keywords:** Potassium; nutrient; safflower; vertisols.

## 1. INTRODUCTION

Potash (K) fertilization started in the 19<sup>th</sup> century when Justus V. Liebig discovered that plants need different proportions and quantities of nutrients such as nitrogen, phosphorous and potassium is an essential element for plant growth. The quantity of potassium adsorbed by root is second to that of nitrogen for most cultivated plants. In India, until the eighties, potassium did not receive much attention because of the general belief that Indian soils were well supplied with potassium. There were several reasons for the lack of interest in potassium fertilization. Firstly, experiments conducted till the fifties did not bring out clear cut crop responses to potassium but now the crop showed significant responses to potassic fertilizer in potash sufficient and deficient soils.

Safflower [*Carthamus tinctorius L. Moench*] is a very useful oilseed crop for rainfed or dryland agriculture. Generally it is known as *Kusum* or *Kardi*. Safflower is a member of the family *Compositae* and originally grown for the flowers that were used in making red and yellow dyes. In India the crop has traditionally been grown in the '*Rabi*', season. Safflower has a promising future as a salinity and drought resistant crop that has both spring and autumn types.

Potassium levels in soil can significantly impact the availability of other essential nutrients like nitrogen, phosphorus and micronutrient. Potassium plays a crucial role in both fixation and availability of nutrients. It's essential for overall plant health and growth, impacting nutrient uptake, root development and resilience to environmental stressors. Specifically potassium enhanced the availability of other nutrients like nitrogen and phosphorus, improves water absorption and support strong root

systems, which are vital for nutrient uptake and fixation.

Potassium application is crucial for safflower growth and yield, significantly impacting various aspects of plant development and stress tolerance. Various doses of potassium contacting fertilizers resulted significant increase in the yield of different cropping systems under fertilizer experiment conduct at various locations in India revived that higher levels of potassium contacting fertilizers input recorded higher yield indicating soils even having higher potassium status responded externally applied potassium. In view of this is needed to study of potassium dynamics in relation release behaviour of potassium, so that the optimum potash dose could be defined. I studied Vertisol soil having high potassium status > 500 kg ha<sup>-1</sup> gives the positive response to application of higher level *i.e.* 100 kg ha<sup>-1</sup> potassium fertilizer, So that to decide the optimum does of potassium for very high K containing Vertisols.

## 2. MATERIALS AND METHODS

A field experiment was conducted during *rabi* seasons of the year 2022-2023 and 2023-24 to study the "Effect of Various Levels of Potassium on K-Adsorption and Release Behaviour under Safflower in Vertisol" on the research farm of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. The experiment was set up using a randomized block design with three replications and ten treatment combinations, with the different treatments being distributed at random within each replication. The soil of the experimental field was characterized by black colour dominated by montmorillonite clay with high coefficient of expansion and shrinkage in summer which leads to deep cracking, alkaline reaction (pH 7.81) with low levels of organic

carbon (0.51 g kg<sup>-1</sup>), available N(184.26 kg/ha), P (12.63 kg/ha) and higher levels of K (511.20 kg/ha).

The treatment combinations are T<sub>1</sub> – Control (Without fertilizer), T<sub>2</sub> – RDF (recommended dose of fertilizer) 60:40:00 NPK kg ha<sup>-1</sup>, T<sub>3</sub> - 100% RDF + 10 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>4</sub> - 100% RDF + 20 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>5</sub> - 100% RDF + 30 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>6</sub> - 100% RDF + 40 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>7</sub> - 100% RDF + 50 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>8</sub> - 100% RDF + 60 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>9</sub>- 100% RDF + 75 Kg K<sub>2</sub>O ha<sup>-1</sup>, T<sub>10</sub> – 100% RDF + 90 Kg K<sub>2</sub>O ha<sup>-1</sup>. Fertilizers were broadcasted and mixed well in the top 15 cm of soil. For the safflower crop half of the recommended dose of nitrogen and full dose of phosphorous and potassium was applied at the time of sowing and remaining half dose of N was applied 30 days after sowing. All the treatments urea, single superphosphate (SSP) and muriate of potash (MOP) were used as a source of NPK. In T<sub>1</sub> (absolute control) treatment neither manure nor chemical fertilizer were applied. Seeds were hand-planted in 7.20 × 5 m plots using the factorial randomized block design with three replications. The seeds were sown in rows with row to row spacing of 45 cm. Plant to plant distance of 20 cm.

## 2.1 Physical Properties

1. **Bulk density:** Bulk density of soil was estimated by clod coating method as described by Piper (1996).
2. **Partical density:** Partical density of soil was estimated by pycnometer method as described by Das and Agarwal (1997).
3. **Porosity:** Porosity determined by using formula,

$$\text{Porosity} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100$$

## 2.2 Chemical Properties

1. **Soil pH:** Hydrogen ion activity expressed as pH was measured on digital pH meter using 1:2.5 (soil: water) suspension (Jackson, 1973).
2. **Electrical Conductivity:** The clear supernatant obtained from the suspension used for pH was utilized for the EC measurement using digital conductivity meter (Jackson, 1973).
3. **Organic carbon:** Organic carbon in soil was estimated by Walkley and Black's rapid titration method as described by Piper (1966).

4. **Calcium Carbonate:** Calcium carbonate was estimated by Rapid Titration method suggested by Jackson (1973).
5. **Available Nitrogen:** It was estimated using alkaline permanganate method as suggested by Subbiah and Asija (1956).
6. **Available Phosphorous:** It was determined by using 0.5 M sodium bicarbonate as an extractant as outlined by Olsen et al. (1954).
7. **Available Potassium:** It was determined by using neutral normal ammonium acetate as an extractant and measured on flame photometer (Piper, 1966).
8. **Available Sulphur:** It was determined by using turbidimetry method and measured on spectrophotometer as described by Chopra and Kanwar (1976).
9. **DTPA Micronutrient:** DTPA extractable zinc, iron, manganese and copper in soil were estimated as per procedure described by Lindsay and Norvell (1978) on Atomic Absorption Spectrophotometer (AAS) at different specified wavelengths.
10. **Statistical Analysis:** The results obtained was statistically analyzed and appropriately interpreted as per the method described in "Statistical Methods for Agricultural Workers" by Panse and Sukhatme, (1985).

## 3. RESULTS AND DISCUSSION

### 3.1 Effect of Various Levels of Potassium on Physico-chemical Properties of Soil at Flowering and after Harvest of Safflower

#### 3.1.1 Bulk density

The data presented in Table 1 revealed that there was no significant change in bulk density both the years due to the application of graded levels of potassium to safflower crop. The bulk density values ranging from 1.38 to 1.44 (g cm<sup>-3</sup>) at flowering and after harvest stage of crop, similar results reported by Chethan et al., (2018) showed that the results indicate that the some of the Important parameter on physical and chemical properties on Pea crop. NPK and Zn fertilizers conjunction on bulk density, particle density and pore space to be non-significant. The bulk density (Mgm<sup>-3</sup>), particle density (Mgm<sup>-3</sup>) and pore space (%) of postharvest soil was recorded 1.21, 2.50 and 49.67 with the treatment (N<sub>40</sub>P<sub>80</sub> K<sub>40</sub> Kg ha<sup>-1</sup>+ Zn 20 kg ha<sup>-1</sup>) respectively. The slight decreased in bulk density, particle

density and pore space may be due to tillage operation and increase in plant growth.

### 3.1.2 Particle density

The data showed in Table 1 revealed that there was no significant change in particle density during both the years due to the application of graded levels of potassium to safflower crop. The particle density values ranged between 2.69 to 2.75 ( $\text{g cm}^{-3}$ ) at flowering and after harvest stage of crop, this may be due to without addition at organic matter similar results represented by Serawat et al., (2018) The field experiment was laid out in a Randomized Block Design with nine treatment combinations, consisting of three N, P K levels (0, 25 and 50%) and Molybdenum (0, 25 and 50%). The treatment T<sub>8</sub> [50% NPK  $\text{ha}^{-1}$  + 50% Molybdenum] showed that bulk density, particle density and pore space not influenced significantly due to application of various treatments.

### 3.1.3 Porosity

The data showed in Table 1 revealed that there was no significant change in porosity due to the application of graded levels of potassium to safflower crop during both the years. The porosity values ranged between 46 to 48% at flowering and harvesting stage of safflower.

### 3.1.4 Soil pH

pH is an important property of soil which usually does not change easily particularly in Vertisols. The effect of various levels of potassium on periodical changes on soil pH in safflower crop is narrated in Table 2. The soil pH determined at flowering and after harvest stage of safflower crop. In season *Rabi*- 2022-23 and 2023-24 soil pH was ranges from (7.67 to 7.84, 7.74 to 7.87) (7.61 to 7.84, 7.63 to 7.86) at flowering and after harvest stage of crop. Observed in soil reaction was not influenced significantly due to application of various levels of potassic fertilizers. Soils were in alkaline range with a mean pH value of 7.77 and 7.73 at flowering and after harvesting stage, respectively. The soil pH slightly increased at harvesting stage of crop. This may be due to precipitation of salt on soil surface. However, there was numerical increase or decrease in soil pH. At flowering and at harvest stage there was slight increase in soil pH as a result of application of chemical fertilizers as compared to initial value. Similar result found by Mali et al., (2017) the effect of different level of potassium was

found to be non-significant in respect of soil pH. The pH value ranged from 7.78 to 7.92 indicating slight variation. The high soil pH might be due to presence of high degree of base saturation. Similar findings were also reported Lokya et al., (2021) the pH value ranged from 7.78 to 7.92 indicating slightly alkali soils.

Hussain et al., (2023) reported that the effect of different levels of potassium on soil pH value 8.24 after harvest was found non-significant.

### 3.1.5 EC (Electrical conductivity)

The data presented in Table 2 revealed that both the years there was no significant change in electrical conductivity due to the application of various levels of potassium to safflower crop. The EC values ranging from 0.21 to 0.28  $\text{dSm}^{-1}$  at flowering and after harvest stage of crop, there by indicating that these soils are enough in soluble salts. The safe soluble salts concentration. The electrical conductivity slightly increased at harvesting stage as compare to flowering stage. The results were in conformity with the findings reported by Waghmare et al., (2008) value ranged from 0.28 to 0.33  $\text{dSm}^{-1}$  for the soil is free from salinity and alkalinity and also Similar result found by Mali et al., (2017) the effect of different level of potash on electrical conductivity was found to be non-significant. The electrical conductivity value ranged from 0.28 to 0.33  $\text{dSm}^{-1}$  for various treatments indicating slight variation among various potassium levels and the soil is free from salinity and alkalinity. Hussain et al., (2023) the data pertaining to the effect of different treatments of potassium on soil pH and EC after harvest was found non-significant.

### 3.1.6 Calcium carbonate

The calcium carbonate levels during the *rabi* seasons of 2022-23 and 2023-24 exhibited variability, ranging from 5.57% to 7.83% and 5.40% to 7.87% at the flowering and harvesting stages, respectively, for the former, and from 5.42% to 7.12% and 5.50% to 7.78% for the latter, as detailed in Table 2. The application of different potassium treatment levels did not significantly affect the  $\text{CaCO}_3$  content, although there were observable fluctuations. The calcareous characteristics of the soil, combined with the prevalence of montmorillonite clay, significantly impact nutrient availability for plants. The  $\text{CaCO}_3$  levels remained relatively stable over a single crop season due to the high buffering

capacity of black soils. Deshmukh et al., (2018) reported similar findings, indicating that the soils in the study area had a low organic carbon content of 0.36% and a free calcium carbonate level of 5.20%. The soils were neutral to slightly alkaline, with a pH range of 7.24 to 7.69, and the application of various treatments did not lead to significant changes post-harvest. Adsure et al., (2018) reported that at the harvesting stage of black gram  $\text{CaCO}_3$  was not influenced significantly due to application of various levels of graded potassium.

### 3.1.7 Organic carbon

The data regarding soil organic carbon present in Table 2 was increased significantly due to RDF (NP) + different potassium treatments. During *rabi*-2022-23 maximum organic carbon found in treatment  $T_{10}$  (100% RDF + 90 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) (0.74 and 0.75%) at par with the treatment  $T_9$  (100% RDF + 75 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ),  $T_8$  (100% RDF + 60 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) and  $T_7$  (100% RDF + 50 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) however, minimum organic carbon content in soil was recorded with treatment  $T_1$  control (0.54 and 0.55%) at flowering stage and after harvest stage of safflower.

In season *rabi*-2023-24 maximum organic carbon found in treatment  $T_{10}$  100% RDF + 90 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$  (0.73 and 0.74%) at par with the treatment  $T_9$  100% RDF + 75 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ,  $T_8$  100% RDF + 60 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$  and  $T_7$  100% RDF + 50 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$  however, minimum organic carbon in soil was recorded with treatment  $T_1$  control (0.54 and 0.55) and pooled mean of the both the years highest value of organic carbon was observed in  $T_{10}$  100% RDF + 90 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$  (0.74 and 0.75) at par with the treatment  $T_9$  100% RDF + 75 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ,  $T_8$  100% RDF + 60 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$  and  $T_7$  100% RDF + 50 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ .

This may be due to which was increased with increasing dose of fertilizer. However also detect that organic carbon content increased at harvesting stage as compare to flowering stage of safflower. Shillode et al., (2016) found that the application of 100% recommended dose of fertilizers (RDF) resulted in an increase in soil available organic carbon to 6.1 g  $\text{kg}^{-1}$ . Similarly, Adsure et al., (2018) observed an increase in organic carbon to 6.01 g  $\text{kg}^{-1}$  with the application of varying levels of potassium alongside nitrogen and phosphorus. Lokya et al., (2021) examined the effects of different potassium levels on soil organic carbon, revealing that the organic carbon content ranged from 5.50 to 5.67 g  $\text{kg}^{-1}$ , with the

highest content (5.67 g  $\text{kg}^{-1}$ ) resulting from the application of 30:75:90 kg NPK  $\text{ha}^{-1}$ , followed closely by 30:75:60 kg NPK  $\text{ha}^{-1}$ . Which found to be on par with each other. The lowest value of organic carbon (5.50 g  $\text{kg}^{-1}$ ) was recorded with the application of 30:75:00 kg NPK  $\text{ha}^{-1}$ .

## 3.2 Effect of Various Levels of Potassium Application on Available Nutrients Status of Safflower at Flowering and Harvesting Stage of Safflower

### 3.2.1 Available nitrogen

A perusal of data presented in Table 3 indicates that available nitrogen was significantly increased with application of various levels of potassium. During *Rabi*-2022-23 and 2023-24 highest available N in the soil of safflower crop at flowering stage (206.57, 204.85, 202.93 and 200.67 kg/ha) and (207.24, 205.74, 203.37 and 201.33 kg  $\text{ha}^{-1}$ ) and after harvest stage of safflower (202.94, 200.98, 199.33 and 197.85 kg  $\text{ha}^{-1}$ ) and (203.93, 201.86, 200.25 and 198.52 kg  $\text{ha}^{-1}$ ) was found in treatment  $T_{10}$  (100% RDF + 90 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) at par with the treatment  $T_9$  (100% RDF + 75 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ),  $T_8$  (100% RDF + 60 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) and  $T_7$  (100% RDF + 50 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) and the lowest value of available N found in control treatment  $T_1$  Control (Without fertilizer) .

The pooled mean of two years data "n sa'flower crop revealed that available N significantly more at flowering stage (206.91, 205.30, 203.15 and 201.00 kg  $\text{ha}^{-1}$ ) and after harvest stage of crop (203.435, 201.42, 199.79 and 198.18 kg  $\text{ha}^{-1}$ ) highest value was found in treatment  $T_{10}$  (100% RDF + 90 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) at par with the treatment  $T_9$  (100% RDF + 75 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ),  $T_8$  (100% RDF + 60 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) and  $T_7$  (100% RDF + 50 Kg  $\text{K}_2\text{O}$   $\text{ha}^{-1}$ ) and the lowest value of available N found in control treatment  $T_1$  Control (Without fertilizer) and harvesting stage.

The availability of nitrogen in soil was increased due to inorganic fertilizer levels, which released nitrogen by mineralization process and become available to growing crop. Shillode et al., (2016) reported similar findings, noting that the use of 100% Recommended Dose of Fertilizer (RDF) increased soil nitrogen availability to 228.76 kg  $\text{ha}^{-1}$ . Additionally, Ripan Chandra Das et al., (2017) found that the application of RDF at a ratio of 40:40:12 kg  $\text{ha}^{-1}$  for NPK resulted in a significant increase in available nitrogen, measuring 203.47 kg  $\text{ha}^{-1}$  after safflower harvest. It was also noted that the use of potassic

fertilizers further enhanced nitrogen availability, likely due to the reduction of nitrogen fixation when applying 100% RDF along with 90 kg K<sub>2</sub>O ha<sup>-1</sup>, thereby improving nitrogen efficiency. Lokya et al., (2021) studied that the available N, P and K was improved significantly with the application of 90 kg K<sub>2</sub>O ha<sup>-1</sup> along with recommended dose of N and P.

### 3.2.2 Available phosphorus

The pooled mean of two years data on safflower crop revealed that the data presented in Table 3 indicates that available phosphorus in soil was positively significant increased with the application of various levels of potassic fertilizers along with RDF in safflower. The available phosphorus at flowering stage observed in (20.46, 19.84, 19.54 and 19.42 kg ha<sup>-1</sup>) and after harvest stage of crop (18.58, 18.20, 18.05 and 17.69 kg ha<sup>-1</sup>) in both stages available phosphorus highest observed in treatment T<sub>10</sub> (100% RDF + 90 Kg K<sub>2</sub>O ha<sup>-1</sup>) at par with by the treatment T<sub>9</sub> (100% RDF + 75 Kg K<sub>2</sub>O ha<sup>-1</sup>), T<sub>8</sub> (100% RDF + 60 Kg K<sub>2</sub>O ha<sup>-1</sup>) and T<sub>7</sub> (100% RDF + 50 Kg K<sub>2</sub>O ha<sup>-1</sup>) and the lowest value of available P found in control treatment T<sub>1</sub> Control (Without fertilizer).

In season *Rabi*-2022-23 and 2023-24, higher available phosphorus in soil at flowering stage was noticed in application of treatment T<sub>10</sub> 100% RDF + 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (20.50 and 20.41 kg ha<sup>-1</sup>) which was at par with the treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (20.17 and 19.50 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (19.83 and 19.24 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (19.77 and 19.07 kg ha<sup>-1</sup>). After harvest stage of crop higher available P in soil was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (18.83 and 18.32 kg ha<sup>-1</sup>) at par with the treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (18.67 and 17.73 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (18.50 and 17.60 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (17.86 and 17.52 kg ha<sup>-1</sup>).

In our experiment finding indicates that increased availability of phosphorus with RDF along with potassic fertilizers this might be due to rapid solubilisation of native and applied phosphorus results of the carbonic acid produced due to higher microbial respiration, protection provided by humic substances. Shillode et al., (2016) similarly reported that the application of 100% RDF raised soil phosphorus availability to 16.10

kg ha<sup>-1</sup>. Furthermore, Ripan Chandra Das et al., (2017) observed that the application of RDF (40:40:12 kg ha<sup>-1</sup> NPK) significantly increased available P<sub>2</sub>O<sub>5</sub> in the soil to 12.64 kg ha<sup>-1</sup> after safflower harvest. The application of potassic fertilizers was also found to enhance P<sub>2</sub>O<sub>5</sub> availability, likely due to the improved efficiency of phosphorus resulting from K-containing fertilizers. Serawat et al. (2018) reported that the effect of different levels of N, P, K and Mo gives significantly higher Phosphorus (30.80 kg ha<sup>-1</sup>) with application of 50% NPK + 50% Molybdenum.

### 3.2.3 Available potassium

Data presented in Table 3 indicates that available potassium in soil was positively and significantly increased with combination of RDF along with various levels of potassium in safflower.

In *Rabi*-2022-23 and 2023-24, higher available potassium in soil at flowering stage was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (707.33 and 702.19 kg ha<sup>-1</sup>) which was at par with treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (702.27 and 698.67 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (697.75 and 695.33 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (695.83 and 694.67 kg ha<sup>-1</sup>). After harvest stage of crop higher available K in soil was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (704.10 and 698.19 kg ha<sup>-1</sup>) which was at par with the treatment T<sub>9</sub> 100% RDF along with 75 Kg potassium ha<sup>-1</sup> (696.83 and 695.04 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (695.17 and 692.75 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (694.33 and 691.74 kg ha<sup>-1</sup>).

In two years calculated pooled mean observation stated that higher available potassium in soil at flowering stage and after harvest stage of crop was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (704.76 and 701.15 kg ha<sup>-1</sup>) which was at par with treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (700.47 and 695.94 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (696.54 and 693.96 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (695.25 and 693.04 kg ha<sup>-1</sup>).

The increase in potassium availability in the soil, characterized by high K<sub>2</sub>O content, is attributed

to the presence of potassium-rich minerals found in the Vertisols and related soils of the Marathwada region (Vineetha and Malewar, 2009). Achieving balanced nutrition, particularly in terms of nitrogen and potassium, and leveraging the synergistic effects between these nutrients is crucial for enhancing nutrient use efficiency in crop production systems (Kurahde et al., 2015). Dhule et al., (2014) also observed higher available potassium with the application of 50 kg K<sub>2</sub>O ha<sup>-1</sup> along with recommended N and P<sub>2</sub>O<sub>5</sub>. Paramasivan et al., (2018) recorded the effect of different levels of N, P, K on soil fertility of rice (*Oryza sativa* L) gives the significant results in available K (362.7 kg/ha) status in soil with the application of 200: 75: 75 kg N: P: K ha<sup>-1</sup>.

### 3.2.4 Available sulphur

The result pertaining to the effect of various levels of potassic fertilizers along with RDF on soil available sulphur are narrated in Table 4. The data indicated that the soil available sulphur was found in the *rabi*- 2022-23 and 2023-24 higher available sulphur in soil at flowering stage was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.33 and 27.81 kg ha<sup>-1</sup>) which was at par with treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.24 and 27.70 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.08 and 27.49 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (26.79 and 27.35 kg ha<sup>-1</sup>). After harvest stage of crop higher available sulphur in soil was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (25.83 and 26.20 kg ha<sup>-1</sup>) which was at par with treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (25.60 and 25.80 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (25.34 and 25.52 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (25.08 and 25.49 kg ha<sup>-1</sup>).

In two years calculated pooled mean observation stated that higher available sulphur in soil at flowering and after harvest stage of crop was noticed in application of treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.57 and 26.02 kg ha<sup>-1</sup>) which was at par with treatment T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.47 and 25.70 kg ha<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.29 and 25.43 kg ha<sup>-1</sup>) and treatment T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (27.07 and 25.29 kg ha<sup>-1</sup>).

The result might that due to the application of single super phosphate which contained about

12 Per cent of sulphur. The similar results was observed by Arbad and Syed Ismail (2011) and Katkar et al., (2011) in long term fertilizer experiment found that the availability of sulphur was increased in soil with the application of balanced fertilizers in Vertisol.

## 3.3 Effect of Various Levels of Potassium on DTPA Extractable Soil Micronutrient at Flowering and after Harvest of Safflower

### 3.3.1 Zinc

The data pertaining to DTPA extractable Zn is narrated in Table 4 which was significantly and positively influenced due to application of different levels of potassium along with RDF in safflower. DTPA zinc ranged between (0.77 to 1.39 and 0.72 to 1.35 mg kg<sup>-1</sup>) during *rabi*-2022-23, (0.76 to 1.38 and 0.70 to 1.27 mg kg<sup>-1</sup>) during *rabi*- 2023-24 and calculated pooled mean ranges (0.77 to 1.39 and 0.71 to 1.31 mg kg<sup>-1</sup>) showing significantly higher DTPA zinc in treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> showed maximum Zn availability at par with T<sub>9</sub> 100% RDF along with K<sub>2</sub>O ha<sup>-1</sup>, treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> and T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> at flowering and after harvest stage of safflower. Soils typically exhibit low levels of available zinc (Zn) and show a positive response to fertilizer applications. In black soils, zinc deficiency is often attributed to the presence of calcium carbonate, which reduces zinc availability due to elevated soil pH levels. This phenomenon may occur because, under alkaline conditions, zinc cations tend to bond with oxides or hydroxides, thereby diminishing zinc availability. These observations align with the research conducted by Kannan et al., (2014).

### 3.3.2 Ferrous

Results narrated in Table 4 related to DTPA iron in safflower indicate significant effect of various levels of potassic fertilizers along with RDF. Effect of various levels of potassium on DTPA ferrous at flowering and after harvest stage of crop showing significantly higher in ranged between (4.09 to 5.93 and 3.89 to 5.52 mg kg<sup>-1</sup>) during *rabi*-2022-23, (4.11 to 5.60 and 3.77 to 5.29 mg kg<sup>-1</sup>) during *rabi*- 2023-24 and (4.10 to 5.77 and 3.83 to 5.41 mg kg<sup>-1</sup>) calculated pooled mean. In treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> showed maximum ferrous availability at par with T<sub>9</sub> 100% RDF along with K<sub>2</sub>O ha<sup>-1</sup>,

**Table 1. Effect of various levels of potassium application on bulk density, particle density and porosity of soil at harvesting stage of safflower crop in Vertisol**

Treatments	Treatment details	Pooled data					
		Flowering			Harvesting		
		BD (g cm <sup>3</sup> )	PD (g cm <sup>3</sup> )	Porosity (%)	BD (g cm <sup>3</sup> )	PD (g cm <sup>3</sup> )	Porosity (%)
T <sub>1</sub>	Control (Without fertilizer)	1.44	2.72	47.02	1.44	2.74	47.35
T <sub>2</sub>	RDF 60:40:00 NPK kg ha <sup>-1</sup>	1.37	2.71	49.44	1.38	2.71	49.345
T <sub>3</sub>	100% RDF + 10 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.39	2.65	47.715	1.39	2.67	47.775
T <sub>4</sub>	100% RDF + 20 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.40	2.67	47.65	1.39	2.68	48.065
T <sub>5</sub>	100% RDF + 30 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.40	2.67	47.67	1.42	2.68	47.23
T <sub>6</sub>	100% RDF + 40 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.35	2.64	49.02	1.36	2.66	49.06
T <sub>7</sub>	100% RDF + 50 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.36	2.65	48.63	1.38	2.66	48.07
T <sub>8</sub>	100% RDF + 60 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.41	2.67	47.265	1.42	2.68	47.155
T <sub>9</sub>	100% RDF + 75 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.40	2.70	48.295	1.41	2.71	48.185
T <sub>10</sub>	100% RDF + 90 Kg K <sub>2</sub> O ha <sup>-1</sup>	1.38	2.68	48.36	1.39	2.70	48.255
SEm (±)		<b>0.03</b>	<b>0.03</b>	<b>2.03</b>	<b>0.03</b>	<b>0.03</b>	<b>1.78</b>
CD at 5%		<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>

**Table 2. Effect of various levels of potassium application on PH, EC OC and CaCO<sub>3</sub> Content in soil at harvesting stage of safflower crop in Vertisol**

Treatments	Treatment details	Pooled data							
		Flowering				After harvest			
		pH	EC	OC	CaCO <sub>3</sub>	pH	EC	OC	CaCO <sub>3</sub>
T <sub>1</sub>	Control (Without fertilizer)	7.83	0.26	0.54	6.04	7.87	0.28	0.54	6.30
T <sub>2</sub>	RDF 60:40:00 NPK kg ha <sup>-1</sup>	7.71	0.24	0.59	5.50	7.75	0.25	0.59	5.45
T <sub>3</sub>	100% RDF + 10 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.73	0.21	0.60	6.60	7.76	0.23	0.60	6.51
T <sub>4</sub>	100% RDF + 20 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.72	0.24	0.60	6.60	7.74	0.25	0.60	6.58
T <sub>5</sub>	100% RDF + 30 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.66	0.23	0.63	5.58	7.70	0.25	0.63	6.04
T <sub>6</sub>	100% RDF + 40 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.69	0.22	0.63	6.59	7.71	0.24	0.63	6.91
T <sub>7</sub>	100% RDF + 50 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.73	0.25	0.62	7.67	7.84	0.26	0.62	7.79
T <sub>8</sub>	100% RDF + 60 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.73	0.22	0.63	7.67	7.74	0.23	0.63	7.72
T <sub>9</sub>	100% RDF + 75 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.77	0.21	0.64	7.17	7.79	0.22	0.64	7.26
T <sub>10</sub>	100% RDF + 90 Kg K <sub>2</sub> O ha <sup>-1</sup>	7.82	0.25	0.74	5.89	7.83	0.26	0.74	5.85
SEm (±)		<b>0.04</b>	<b>0.03</b>	<b>0.030</b>	<b>0.62</b>	<b>0.06</b>	<b>0.02</b>	<b>0.029</b>	<b>0.62</b>
CD at 5%		<b>NS</b>	<b>NS</b>	<b>0.088</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>0.087</b>	<b>NS</b>

**Table 3. Effect of various levels of potassium application on Available NPK (Kgha<sup>-1</sup>) Content in soil after harvesting stage of safflower crop in Vertisol**

Treatments	Treatment details	Pooled data					
		Flowering			After harvest		
		N	P	K	N	P	K
T <sub>1</sub>	Control (Without fertilizer)	186.76	11.92	502.59	184	11.04	495.77
T <sub>2</sub>	RDF 60:40:00 NPK kg ha <sup>-1</sup>	189.58	14.99	541.38	186.075	12.88	533.92
T <sub>3</sub>	100% RDF + 10 Kg K <sub>2</sub> O ha <sup>-1</sup>	191.25	16.57	559.15	187.825	13.70	552.25
T <sub>4</sub>	100% RDF + 20 Kg K <sub>2</sub> O ha <sup>-1</sup>	192.17	17.14	577.75	189.58	14.64	572.71
T <sub>5</sub>	100% RDF + 30 Kg K <sub>2</sub> O ha <sup>-1</sup>	194.81	17.77	676.15	192.71	15.29	671.15
T <sub>6</sub>	100% RDF + 40 Kg K <sub>2</sub> O ha <sup>-1</sup>	197.73	18.53	682.04	194.74	15.79	673.19
T <sub>7</sub>	100% RDF + 50 Kg K <sub>2</sub> O ha <sup>-1</sup>	201.00	19.42	695.25	198.185	17.69	693.04
T <sub>8</sub>	100% RDF + 60 Kg K <sub>2</sub> O ha <sup>-1</sup>	203.15	19.54	696.54	199.79	18.05	693.96
T <sub>9</sub>	100% RDF + 75 Kg K <sub>2</sub> O ha <sup>-1</sup>	205.30	19.84	700.47	201.42	18.20	695.94
T <sub>10</sub>	100% RDF + 90 Kg K <sub>2</sub> O ha <sup>-1</sup>	206.91	20.46	704.76	203.435	18.58	701.15
SEm (±)		<b>2.08</b>	<b>0.39</b>	<b>5.07</b>	<b>1.74</b>	<b>0.45</b>	<b>3.28</b>
CD at 5%		<b>6.19</b>	<b>1.16</b>	<b>15.06</b>	<b>5.17</b>	<b>1.33</b>	<b>9.76</b>

**Table 4. Effect of various levels of potassium application on S, Fe, Zn, Cu & Mn Content in soil at harvesting stage of safflower crop in Vertisol**

Treatments	Treatment Details	Pooled data									
		Flowering					After harvest				
		S	Fe	Zn	Cu	Mn	S	Fe	Zn	Cu	Mn
T <sub>1</sub>	Control (Without fertilizer)	18.70	4.10	0.77	1.96	6.08	16.20	3.83	0.71	1.88	6.12
T <sub>2</sub>	RDF 60:40:00 NPK kg ha <sup>-1</sup>	21.34	4.27	0.89	2.10	6.90	18.92	4.06	0.84	2.00	6.78
T <sub>3</sub>	100% RDF + 10 Kg K <sub>2</sub> O ha <sup>-1</sup>	22.43	4.57	0.99	2.44	7.16	19.69	4.17	0.92	2.40	7.01
T <sub>4</sub>	100% RDF + 20 Kg K <sub>2</sub> O ha <sup>-1</sup>	22.66	4.39	1.03	2.51	7.26	20.28	4.27	0.94	2.50	7.19
T <sub>5</sub>	100% RDF + 30 Kg K <sub>2</sub> O ha <sup>-1</sup>	23.66	4.60	1.12	2.59	7.38	21.47	4.45	1.07	2.58	7.30
T <sub>6</sub>	100% RDF + 40 Kg K <sub>2</sub> O ha <sup>-1</sup>	24.36	4.79	1.16	2.65	7.58	22.75	4.57	1.11	2.62	7.49
T <sub>7</sub>	100% RDF + 50 Kg K <sub>2</sub> O ha <sup>-1</sup>	27.07	5.47	1.30	2.77	8.46	25.29	4.90	1.22	2.71	8.46
T <sub>8</sub>	100% RDF + 60 Kg K <sub>2</sub> O ha <sup>-1</sup>	27.29	5.56	1.36	2.81	8.58	25.43	5.15	1.25	2.78	8.57
T <sub>9</sub>	100% RDF + 75 Kg K <sub>2</sub> O ha <sup>-1</sup>	27.47	5.68	1.38	2.88	8.68	25.70	5.24	1.28	2.82	8.67
T <sub>10</sub>	100% RDF + 90 Kg K <sub>2</sub> O ha <sup>-1</sup>	27.57	5.77	1.39	2.94	8.88	26.02	5.41	1.31	2.88	8.78
SEm (±)		<b>0.17</b>	<b>0.15</b>	<b>0.05</b>	<b>0.07</b>	<b>0.18</b>	<b>0.26</b>	<b>0.20</b>	<b>0.051</b>	<b>0.072</b>	<b>0.14</b>
CD at 5%		<b>0.51</b>	<b>0.44</b>	<b>0.15</b>	<b>0.21</b>	<b>0.54</b>	<b>0.61</b>	<b>0.60</b>	<b>0.153</b>	<b>0.215</b>	<b>0.41</b>

treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> and T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> at flowering and after harvest stage of safflower as compare to control treatment. Similar result found by Taha et al., (2016) The available nutrients in soil (N, P, K and Fe) increased significantly with increasing dose of potassium fertilizers.

### 3.3.3 Copper

Effect of various levels of potassium along with RDF enhanced the DTPA copper content in the soil narrated in Table 4. The data indicated that various levels of potassium along with RDF influenced significantly DTPA copper at flowering and after harvest stage of crop which range between (1.97 to 2.96 and 1.89 to 2.90 mg kg<sup>-1</sup>) during *rabi*-2022-23, (1.95 to 2.91 and 1.86 to 2.85 mg kg<sup>-1</sup>) during *rabi*- 2023-24, and (1.96 to 2.94 and 1.88 to 2.88 mg kg<sup>-1</sup>) pooled mean showing significantly higher in treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> at par with T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup>, treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> and T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> at flowering and after harvest stage of safflower as compare to control treatment. The elevated copper levels in the soil may be linked to the presence of copper-bearing minerals such as cuprite and chalcocite in the parent material. Similar observations were made by Malewar et al., (1976).

### 3.3.4 Manganese

Effect of various levels of potassium along with RDF enhanced the DTPA manganese content in the soil narrated in Table 4. The data indicated that various levels of potassium along with RDF influenced significantly DTPA manganese. At flowering and after harvest stage of crop which range between (6.13 to 9.03 and 6.38 to 8.92 mg kg<sup>-1</sup>) during *rabi*-2022-23, (6.02 to 8.72 and 5.86 to 8.64 mg kg<sup>-1</sup>) during *rabi*- 2023-24, and (6.08 to 8.88 and 6.12 to 8.78 mg kg<sup>-1</sup>) pooled mean. DTPA manganese showing significantly in treatment T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (9.03 and 8.72 mg kg<sup>-1</sup>) at par with T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.87 and 8.47 mg kg<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.70 and 8.45 mg kg<sup>-1</sup>) and T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.50 and 8.41 mg kg<sup>-1</sup>) at flowering stage both years and after harvest stage of safflower T<sub>10</sub> 100% RDF along with 90 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.92 and 8.64 mg kg<sup>-1</sup>) at par with T<sub>9</sub> 100% RDF along with 75 Kg K<sub>2</sub>O ha<sup>-1</sup>

(8.82 and 8.52 mg kg<sup>-1</sup>), treatment T<sub>8</sub> 100% RDF along with 60 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.63 and 8.50 mg kg<sup>-1</sup>) and T<sub>7</sub> 100% RDF along with 50 Kg K<sub>2</sub>O ha<sup>-1</sup> (8.43 and 8.48 mg kg<sup>-1</sup>) observed both the years. The high manganese content in the soil can be explained by the greater solubility of manganese in its lower oxidation states compared to its higher oxidation states, particularly within the neutral pH range of the soil. These findings are consistent with those reported by Kannan et al., (2014).

## 4. CONCLUSION

The application of various levels of potassic fertilizer with RDF on physical and chemical properties does not give significant results in bulk density, particle density, porosity, pH, EC and calcium carbonate and significantly increased organic carbon content in soil at flowering and after harvest of safflower as compare to initial status of soil. Available nitrogen, phosphorus, potassium, sulphur and DTPA extractable ferrous, zinc, copper and manganese significantly increased with the application of various levels of potassium with RDF to safflower crop.

From above, however concluded that the potassium supplying capacity of soil is not only depends on the available K content of Vertisol but its depends on the K fixation and release behaviour of added fertilizers. The optimum available nutrient status was recorded at application of RDF (60:40:00 kg N, P<sub>2</sub>O<sub>5</sub>) + 50 kg K<sub>2</sub>O ha<sup>-1</sup>. This indicating application of 50 kg potassium with recommended dose of safflower (60:40:00 kg N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O ha<sup>-1</sup>) was found to be beneficial than alone RDF for safflower in Vertisol.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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