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# Stabilized amine nitrogen (SAN) increases tomato (*Solanum lycopersicum* L.) yield under experimental and commercial production

**Sally Wilkinson[1], Jolyon Dodgson[1,2]*, Anna K Weston[1] and David J Marks[1]**

1, *Levity Crop Science, Crowhall Farm, Newsham Hall Lane, Woodplumpton, Preston, PR4 0AS, UK*
2, *Agriculture and Countryside Department, Myerscough College, Bilsborrow, Preston, Lancashire, PR3 0RY*

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***Corresponding author:**
*Levity Crop Science, Crowhall Farm, Newsham Hall Lane, Woodplumpton, Preston, PR4 0AS, UK; Agriculture and Countryside Department, Myerscough College, Bilsborrow, Preston, Lancashire, PR3 0RY.*

**Email:** jolyon@levitycropscience.com



## ABSTRACT

**Purpose:** Excessive nitrogen use for crop production leads to environmental damage, so nitrogen use efficiency (NUE) needs to be improved. Stabilized amine nitrogen (SAN) (Lono, Levity Crop Science) has been shown to increase quality and yield of several crops. This work assesses the use of SAN for tomato production. **Research method:** SAN was applied to experimentally and commercially grown tomato plants and compared to several industry standard forms of nitrogen. Plant growth characters and yield were recorded. **Findings:** SAN was compared to an industry standard (IS) nitrogen fertilizer, and it significantly increased the harvested yield due to significant increases in fruit on trusses M3, M4 and lateral shoots. SAN was compared to several conventional IS fertilizers resulting in significantly increased chlorophyll levels, fruit-bearing trusses and an increased yield, but there was a shorter growth habit suggesting more energy was put towards fruit production and less to vegetative growth. Finally, SAN was applied to commercial processing tomato (variety HZ1662) production where there was a significant increase in the perfect red fruit when compared to the standard nitrogen application regime. **Research limitations:** Further work could be done with other commercial tomato crops. **Originality/Value:** Results from glasshouse experiments and commercial production show that SAN increases the yield of tomato (*Solanum lycopersicum*) when compared to IS nitrogen applications.

## INTRODUCTION

Global food production has already been impacted by climate change (Ray et al., 2019), due to changes in weather conditions and increased plant stress. Agriculture also emits greenhouse gases that cause climate change, being the second greatest global contributor; despite many EU countries reducing their greenhouse gas emissions from agriculture (Mohammed et al., 2020), further work still needs to be done. The use of industrial fertilizers, primarily nitrogen, has enabled remarkable yield increases over the last century, but they are a significant source of emissions during their production and in-field post application (Walling & Vaneeckhaute, 2020). This means that when nitrogen is applied to crops, its use efficiency should be as high as possible, as each hectare of the shrinking area of land available for crop production should be managed to produce the greatest yield possible with the smallest amount of inputs.

Nitrogen is available in several forms that can be applied as fertilizer (ammonium, urea, nitrite and organic amines), but, depending on the environmental conditions, they will all degrade to nitrate within hours or weeks (Wilkinson et al., 2019). Due to this swift degradation, limited field work has been undertaken on the impact of the nitrogen form, and when there has been some, it has focused on nitrate and ammonium (Carlisle et al., 2012). There are highly conserved systems in roots and shoots that let plants access organic nitrogen as urea (Neff et al., 2003; Schimel & Bennett, 2004; Wang et al., 2015). When nitrogen can be maintained as urea and prevented from degrading to nitrate it will be accessible to the plants for longer and will cause damage to the environment. Different forms of nitrogen are processed in different organs or cells in plants and require different amounts of resources to be processed (Andrews et al., 2013; Zerihun et al., 1998). A form of stabilized amine nitrogen (SAN) has been developed and shown to increase root lengths, leaf growth rates and chlorophyll concentrations in ornamental plants, which has led to 25-130% more flowers (Wilkinson et al., 2019). Other work has shown that the same SAN product enhances wheat production (Marks et al., 2020), where the chlorophyll content was increased, root lengths were increased, the tillers were more upright and the tiller bases had increased diameters. In potato (Marks et al., 2018; Wilkinson et al., 2020a; Wilkinson et al., 2020b) the chlorophyll content was increased, shoot growth rate was reduced and there was increased tuber biomass when the SAN product was applied. The common physiological changes identified (increased chlorophyll content, greater root biomass, changes in shoot architecture) result in the plant being able to increase the yield that is produced, thereby increasing the nitrogen use efficiency.

## MATERIALS AND METHODS

Dwarf micro-tomato plants (Solanum lycopersicum L. var. micro-tom) were germinated in modules and then transferred at the two-leaf stage to four liter pots filled with a peat based compost (Sinclair Pro Potting and Bedding Peat Reduced Compost, LS Systems Limited, UK) in a ventilated and heated glasshouse located at Myerscough College, in the northwest of the UK in 2018 and 2019. Initially the compost provided appropriate nutrients to allow optimal growth. Once transferred to pots, all plants were supplemented with half strength industry standard N-P-K (24-8-16) fertilizer, which ensured plants had access to micronutrients and P-K. Plants were watered with tap water as required to maintain soil moisture so that the compost remained moist throughout. For the first experiment there were eight replicates and for the second experiment there were 10 replicates. These plants were used for two glasshouse experiments.

In the first experiment, SAN (Lono, Levity Crop Science) was compared to an industry standard (IS) product (Miracle-Gro, The Scotts Miracle-Gro Company, UK) that had the same nutrient composition, but which did not contain the specific chemistry (LimiN technology) to stabilize the nitrogen. The plants were planted on 22nd Aug 2018, and the nitrogen applications were on 19th Sept and 4th Oct 2018. The SAN and IS matched product were applied at a rate of 5l/ha in 200 L water. The micro tomato plants were grown until fruit had reached maturity and could be harvested. The chlorophyll content was measured in the plant leaves five days after the second nitrogen application using a FieldScout CM 1000 Chlorophyll Meter (Spectrum Technologies Inc., Illinois, USA), which was recorded as an index of the relative chlorophyll content, 0-999 ± 5%. The number of lateral shoots and inflorescences were recorded weekly. Once fruit was being produced, the number of fruit per truss were counted and they were harvested was they reached ripeness. The total fruit weight was calculated at the end of the experiment on 31st Jan 2019. Once all the fruit had been harvested, the length of the tomato plant roots that had grown below the bottom of the pot and into the tray holding the irrigation water was measured with a ruler .

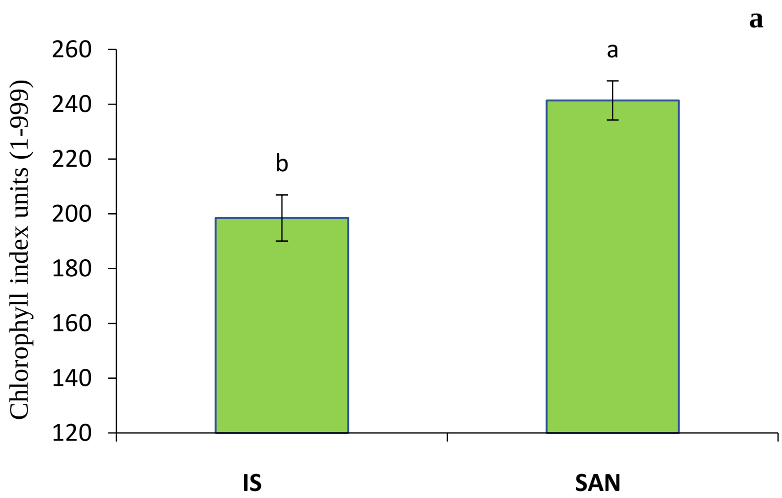
In the second glasshouse experiment, SAN was compared to several conventional IS fertilizers, which were standard N-P-K (24-8-16) (referred to as the control) (Miracle-Gro, The Scotts Miracle-Gro Company, UK), un-stabilized urea (SU), calcium nitrate (CaNO3) and ammonium nitrate (NH4NO3). The plants were planted on 25th July 2019, and the nitrogen applications were on 22nd Aug and 5th Sept 2019. SAN was applied at a rate of 5l/ha in 200 L water. The SAN contained 15% N by weight, and all other treatments were applied at rates to supply the same amount of nitrogen. The micro tomato plants were grown until the fruit could be harvested. The chlorophyll content was measured on 10th Sept 2019 using the same method as for the first glasshouse experiment and the plant heights were measured with a ruler from the soil to the highest part of the plant on 17th Sept 2019. The number of fruit bearing trusses and harvested fruit weight was recorded on 17th Sept and 21st Nov 2019, respectively .

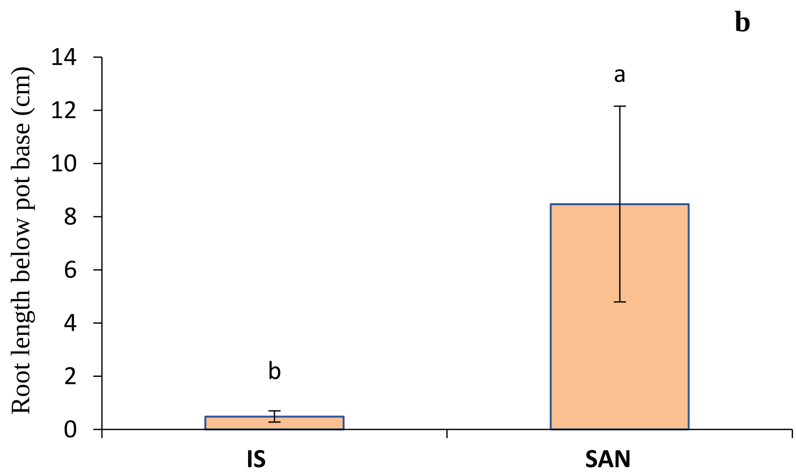
A field experiment was conducted in 2020 with Omex USA and T&P Farms (Arbuckle, California, USA) (soil Westfan loam, cation-exchange capacity 9-31 meq/100g, pH 6.6-8.4, calcium carbonate 0-5%, gypsum 0-1%, salinity 0-2 mmhos/cm, sodium adsorption ratio 0-6, USDA) on processing tomato (variety HZ1662) production where SAN was applied three times (twice via drip (9.4 l/ha on 09.06.20 and 01.07.20) and once via foliar application (2.3 l/ha on 11.08.20)) and compared to the grower's standard nitrogen application regime (CAN17 187 l/ha on 28.05.20, UN37 140 l/ha on 08.06.20, CAN17 187 l/ha on 18.06.20, CAN17 187 l/ha on 02.07.20). The total yield, number of red fruit, number of green fruit and amount of rejects were recorded. The SAN was applied to an area of 4.5 x 390 m (three beds x 390 m) and compared to a comparable area of the grower's standard nitrogen application regime. The center bed for the entire length of the plot was machine harvested and two 15L samples were taken for quality grading where the salable yield (red fruit) and rejects (green fruit and those with black mold or sunburn) were determined.

All results are displayed as means and standard errors. Shapiro-Wilk analysis was used to determine if the data were normally distributed, and one-tailed Students t-tests and Mann-Whitney U tests were used to identify significant differences between treatments at the $p<0.05$ level (unless noted as $p<0.1$). Jamovi 1.6.23 for Windows was used to conduct the statistical analysis.

## RESULTS

In the first glasshouse experiment tomato plants were grown from seed to harvest and had SAN or an IS matched product excluding the technology to stabilize the nitrogen applied. The plants that had SAN applied exhibited better growth than the IS plants as the chlorophyll index units were significantly greater (22% increase) (t -3.89, df 26, p<0.001) (Fig. 1a), the roots were significantly longer (1635% increase) (U 0.557, p<0.001) (Fig. 1b), there were significantly more lateral shoots (36% increase) (t -2.31, df18, p=0.033 (Fig. 1c) and there were significantly more inflorescences per plant (71% increase) (t -2.69, df 19, p=0.014) (Fig. 1d). All of which indicates a greater ability of the plant to achieve a higher yield. Figure 2 indicates that this potential to increase the yield would come from larger numbers of fruit on certain trusses. Trusses M1 and M2 had similar fruit numbers between the two types of nitrogen, while for trusses M3 and M4 as well as the lateral branches, there were significantly more fruit per truss with the SAN application than the IS (M3 34.7% increase t -3.264, df 10, p=0.004; M4 31.7% increase t-2.092, df 10, p=0.031; lateral 2100.0% increase t-3.606, df 10, p=0.002). This is supported by Figures 3a and 3b that show significantly greater fruit number (34% increase) and fruit weight (32% increase), respectively, for SAN over IS (3a t -2.53, df 18, p=0.01; 3b t -1.63, df 18, p=0.059); while there is no difference in the average fruit weight (Figure 3c), thereby showing there was a greater yield and no reduction in fruit size.



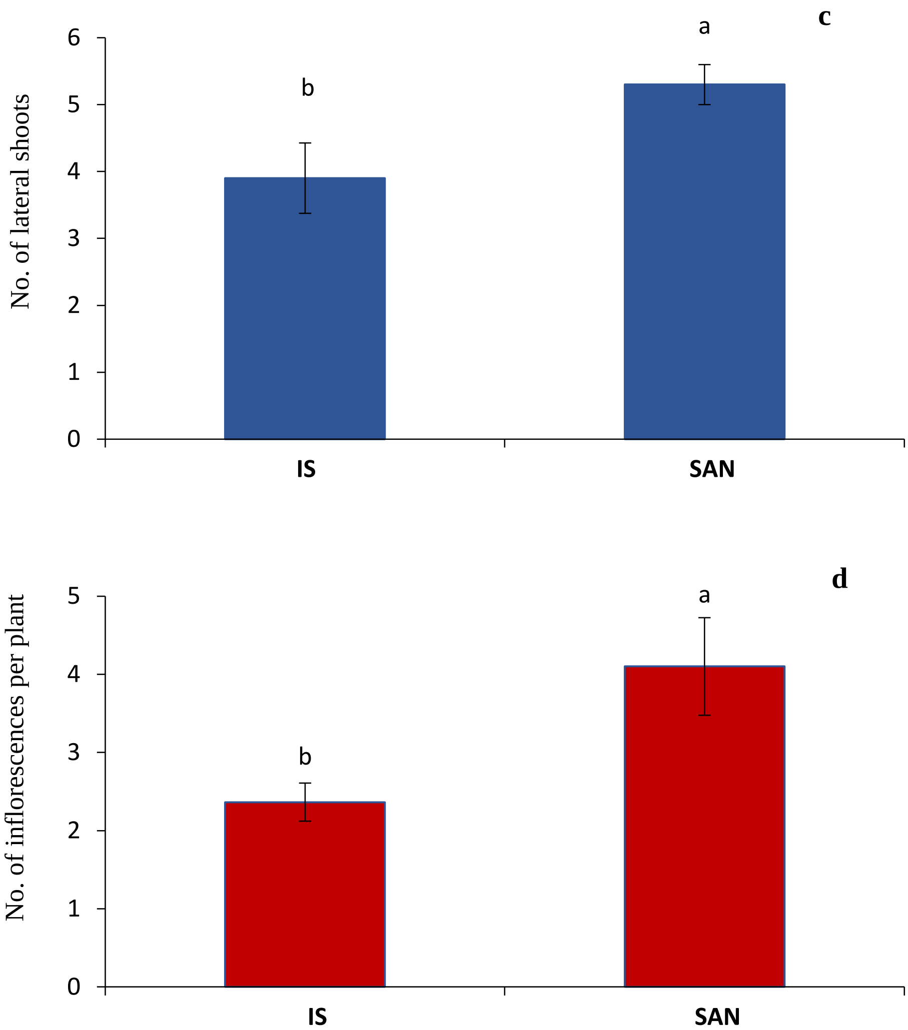



**Fig. 1.** Impact of nitrogen type (industry standard (IS) and stabilized amine nitrogen (SAN)) in experiment 1 on (a) tomato plant leaf chlorophyll index units measured with a FieldScout CM 1000 Chlorophyll Meter (Spectrum Technologies Inc., Illinois, USA); (b) length of tomato plant root that had grown below the bottom of the pot and into the tray holding irrigation water measured once all the fruit had been harvested; (c) number of lateral shoots per plant; and (d) number of inflorescences per plant. Significant differences ($p<0.05$) after Student's t-tests are indicated by lower case letters.

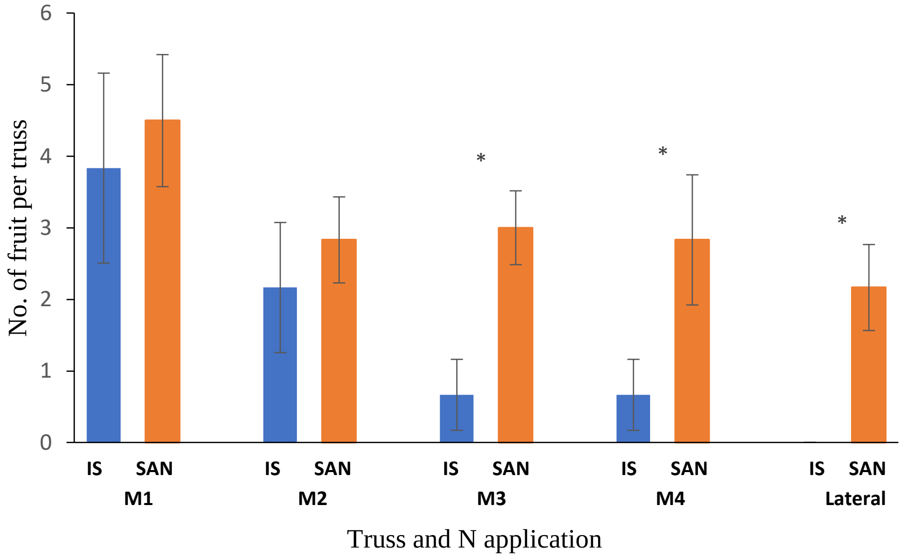



**Fig. 2.** Impact of nitrogen type (industry standard (IS) and stabilized amine nitrogen (SAN)) in experiment 1 on the number of fruit on trusses M1-M4 and lateral branches. Significant differences ($p<0.05$) after Student's t-tests are indicated by * for treatments on each truss or lateral branch.

**Table 1.** From experiment 2, percentage increases or decreases and significant differences for comparisons between stabilized amine nitrogen (SAN) and commonly used nitrogen types (standard N-P-K (control), un-stabilized urea (SU), calcium nitrate ($CaNO_3$) and ammonium nitrate ($NH_4NO_3$) as presented in figure 4a-b after Student's t-tests (* p<0.1 ** p<0.05).

| | Figure 4a | Figure 4b | Figure 4c | Figure 4d |
|---|---|---|---|---|
| SAN:Control | 17.5 % increase<br>* t -1.702, df 14, p=0.055 | 15.4 % decrease<br>** t 3.113, df 14, p=0.004 | 18.4 % increase<br>** t 2.593, df 14, p=0.011 | 18.8 % increase<br>** t -2.022, df 12, p=0.033 |
| SAN:SU | 18.7 % increase<br>** t -1.775, df 13, p=0.05 | 11.3 % decrease<br>** t 1.859, df 13, p=0.043 | 16 % increase<br>* t -1.541, df 13, p=0.074 | 15 % increase<br>* t -1.336, df 12, p=0.1 |
| SAN:$CaNO_3$ | 6.2 % increase<br>t -0.602, df 13, p=0.279 | 7.6 % decrease<br>* t 1.485, df 13, p=0.081 | 31.8 % increase<br>** t -3.033, df 13, p=0.005 | 28.4 % increase<br>* t -1.688, df 12, p=0.059 |
| SAN:$NH_4NO_3$ | 15.6 % increase<br>* t -1.598, df 13, p=0.067 | 10.2 % decrease<br>** t 2.295, df 13, p=0.019 | 23.4 % increase<br>** t 3.250, df 13, p=0.003 | 14.4 % increase<br>* t -1.321, df 12, p=0.1 |

In the second glasshouse experiment tomato plants were again grown from seed to harvest but had a wider range of commonly used forms of nitrogen applied. The SAN treated plants had significantly higher chlorophyll levels (15-17% increases) compared to all the other nitrogen sources apart from the $CaNO_3$ (Fig. 4a) (see Table 1 for details of significant differences and percentage changes in Figure 4). The SAN plant height was significantly shorter (10-15% decreases) than all the other nitrogen forms apart from the $CaNO_3$ (Fig. 4b), which could suggest that less energy was being used on vegetative growth. SAN had significantly more fruit-bearing trusses (16-32% increases) and a greater weight of total fruit harvested (14-28% increases) than the other nitrogen types (Fig. 4c and 4d).

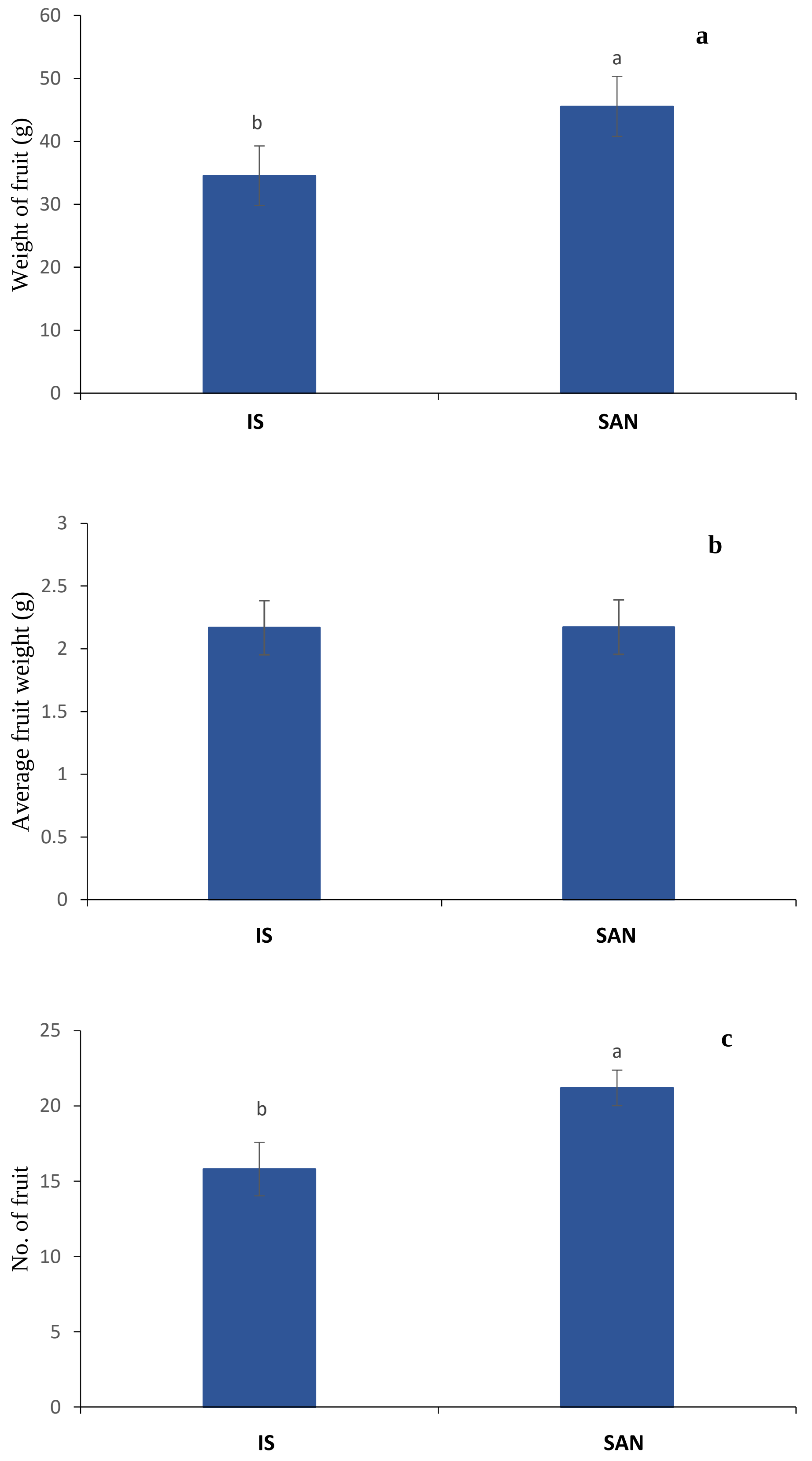
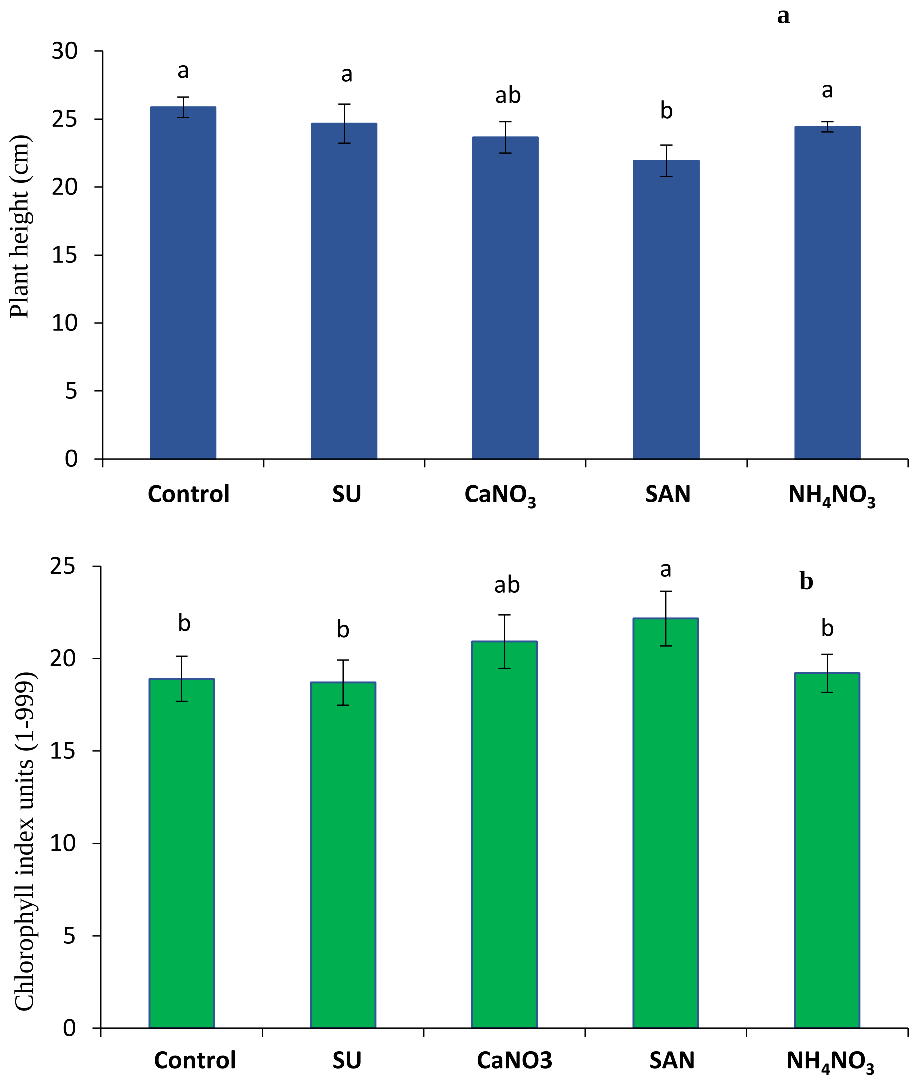



**Fig. 3.** Impact of nitrogen type (industry standard (IS) and stabilized amine nitrogen (SAN)) in experiment 1 on (a) total number of fruit harvested; (b) total weight of fruit harvested; and (c) average weight of each fruit. Significant differences (3a $p<0.05$, 3b $p<0.1$) after Student's t-tests are indicated by lower case letters.


a
Plant height (cm)
30
25
20
15
10
5
0
a
a
ab
b
a
Control
SU
$CaNO_3$
SAN
$NH_4NO_3$
b
Chlorophyll index units (1-999)
25
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Control
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CaNO3
SAN
$NH_4NO_3$

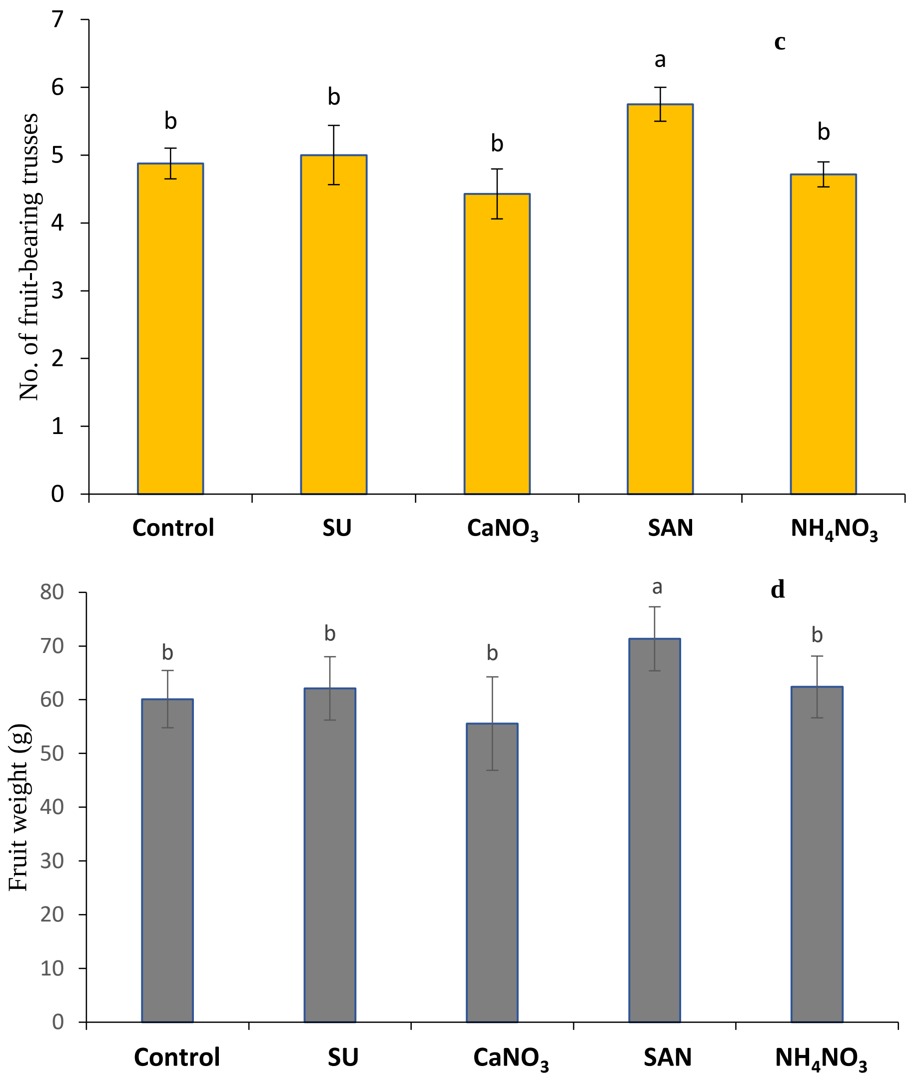
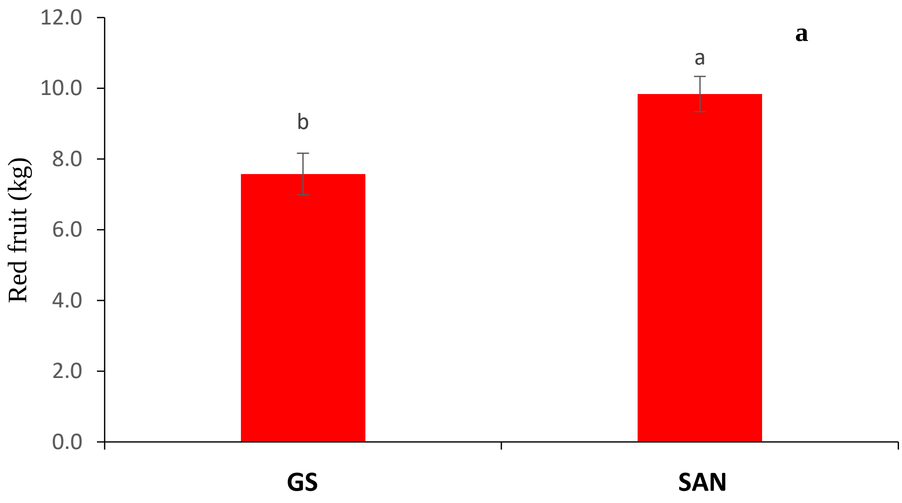



**Fig. 4**. Impact of nitrogen type (standard N-P-K (control), un-stabilized urea (SU), calcium nitrate (CaNO3), stabilized amine nitrogen (SAN) and ammonium nitrate (NH4NO3) in experiment 2 on (a) tomato plant leaf chlorophyll index units measured with a FieldScout CM 1000 Chlorophyll Meter (Spectrum Technologies Inc., Illinois, USA); (b) plant height measured from soil to highest part of the plant; (c) number of fruit bearing trusses; and (d) weight of total harvested fruit. Significant differences ($p<0.05$ or $p<0.1$, see Table 1) after Student's t-tests are indicated by lower case letters.

In 2020, SAN was trialed by a commercial processing tomato grower in Arbuckle, California, USA where three applications of SAN over a season, as part of a complete plant nutrition program, gave significantly increased (29%) red fruit (t 2.94, df 2, p=0.05) (Fig. 5a) and significantly decreased (25%) rejected fruit (t -2.53, df 2, p=0.064) (Fig. 5b), when compared to the grower's standard nitrogen application regime. This shows that the use of SAN can increase the salable yield and quality when used under commercial conditions.



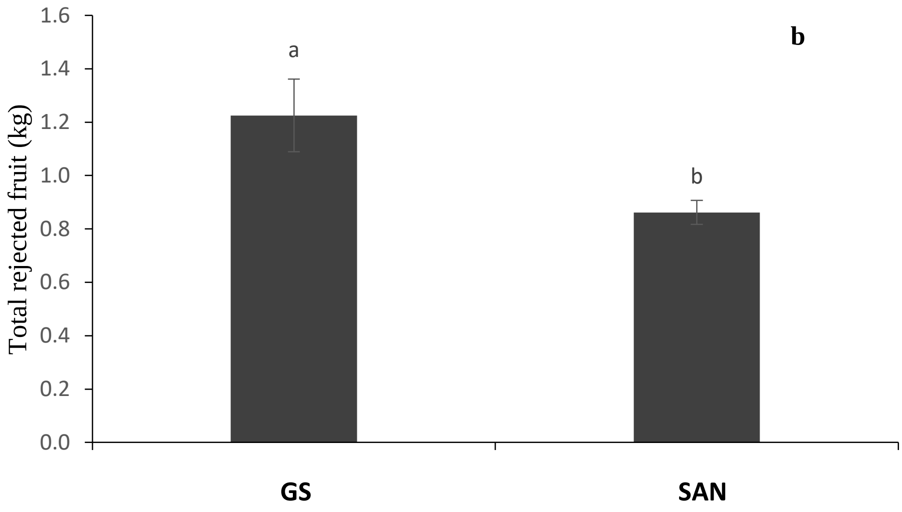




**Fig. 5.** Impact of nitrogen type (grower standard (GS) and stabilized amine nitrogen (SAN)) in field-based experiment on (a) weight of salable red fruit in 15 L sample and (b) total rejected fruit (green fruit and fruit with black mold or sunburn) in 15 L sample. Significant differences (5a $p<0.05$, 5b $p<0.1$) after Student's t-tests are indicated by lower case letters.

## DISCUSSION

The results presented here show that tomato plants treated with SAN when compared to the same amount of nitrogen in the form of an IS nitrogen source had a greater chlorophyll index value, longer roots, increased number of lateral shoots and number of inflorescences (Figures 1a, 1b, 1c and 1d), which is consistent with previous reports about ornamental plants, wheat and potato (Marks et al., 2018, 2020; Wilkinson et al., 2019; Wilkinson et al., 2020a; Wilkinson et al., 2020b). The use of SAN changes the plant's growth habit so it can photosynthesize more, reach more nutrients in the growing medium and use less energy in unproductive vegetative growth, which was demonstrated in Figure 2. The tomato plants treated with SAN had significantly increased fruit on trusses M3 and M4 as well as on the lateral branches. The SAN treated plants produced the same number of fruit on trusses M1 and M2 as did the IS treated plants, but the IS treated plants had only one or zero fruit on trusses M3 and M4 as well as the lateral branches, compared to about three fruit per truss for the SAN treated plants. The increased number of fruit on the trusses resulted in a significantly greater number and weight of fruit produced by the SAN treated plants (Fig. 3a and 3b). The average weights of the fruit produced by the SAN and IS treated plants were the same (Fig. 3c), which shows that the increase in the number of fruit was not achieved due to a reduction in the size of individual fruit. The SAN application was able to increase the number of fruit while maintaining quality, which translates into a greater overall yield from the same amount of nitrogen being applied, therefore increasing the nitrogen use efficiency.

The form of nitrogen has an impact on how and where the plant is able to use it (Andrews et al., 2013; Zerihun et al., 1998). This means that some forms of nitrogen could be less energy efficient for plant growth, as more energy is used by the plant to transport the nitrogen around and change it into a usable form. Therefore, several commonly used forms of nitrogen (standard N-P-K (control), un-stabilized urea (SU), calcium nitrate ($CaNO_3$) and ammonium nitrate ($NH_4NO_3$) were compared to SAN. Figure 4a shows that SAN had greater chlorophyll levels than all the other forms of nitrogen apart from calcium nitrate where there was no difference, which confirms the finding from the previous glasshouse experiment reported in this work. SAN was also shown to have a shorter plant height than all the other nitrogen forms apart from calcium nitrate (Fig. 4b), which supports previous work related to ornamental plants, wheat and potato that the application of SAN alters the plant structure so that less energy is used on vegetative growth and transferred to useful reproductive growth (Marks et al., 2018, 2020; Wilkinson et al., 2019; Wilkinson et al., 2020a; Wilkinson et al., 2020b). Figures 4c and 4d show the impact of the greater chlorophyll content and shorter plant height, as the SAN treated plants were able to produce significantly more fruit-bearing trusses and greater fruit weight than all the other forms of nitrogen tested. In a commercial situation, more fruit bearing trusses and a greater fruit weight produced by each plant would result in a greater yield. Growers have several forms of nitrogen available that they can use when producing tomatoes and this experiment has shown that SAN is a good replacement for the most commonly used forms as it gave a higher yield than all of the ones included in this work. This second glasshouse experiment again shows that when the same amount of nitrogen is given to plants in the SAN form, the nitrogen use efficiency was increased as these plants gave a greater yield than the plants that were given the other tested forms of nitrogen.

Finally, the SAN was used under commercial field conditions by a processing tomato producer. The products were applied to plots that were 390m long and three rows wide, with the central row harvested. The marketable fruit (red fruit) yield was significantly increased in the SAN treated plots compared to the grower standard (Fig. 5a), while the rejected fruit was significantly less in the SAN treated plots (Fig. 5b). The rejected fruit consisted of the green fruit as well as those which had been damaged by black mold and sun burn. Tomato production in the USA is facing several challenges (Chanda et al., 2021), one of which is an increasing cost of inputs. The field results presented here show that with the use of SAN, the salable yields could be increased, thereby using the nitrogen inputs more efficiently, which could help to counter the increasing cost of inputs.

## CONCLUSION

These results show that the increase in tomato yield due to SAN application identified in experimental glasshouses, due to increased fruit bearing trusses, number of fruit and weight of fruit produced (Fig. 3a, 3b, 4c and 4d), can be transferred to a commercial setting where the marketable yield of red fruit was increased by 29% (Fig. 5a) and the rejected fruit were decreased by 25% (Fig. 5b), thereby indicating the suitability of SAN as a nitrogen fertilizer for tomato production. When applying the same amount of nitrogen in the SAN form compared to the commonly available industry standard forms of nitrogen, there were yield increases, which shows that using SAN improved the nitrogen use efficiency. This supports previous work (Li et al., 2017) that the use of a stabilized from of urea can offer benefits over traditional nitrogen based fertilizers. SAN can be applied to tomato to increase yield, which supports the findings from ornamental plants, wheat and potato (Marks et al., 2018, 2020; Wilkinson et al., 2019; Wilkinson et al., 2020a; Wilkinson et al., 2020b).

**Author Contributions**

Conceptualization, S.W., J.D., A.W. and D.M.; methodology, S.W, A.W. and D.M.; investigation, S.W.; formal analysis, S.W. and J.D.; writing—original draft preparation, J.D.; writing—review and editing, J.D. and D.M. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest**

In accordance with our ethical obligation as researchers, we are reporting that we are employees of a company that may be affected by the research reported in the enclosed paper. Mention of commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement. Other stabilized N products can be used to carry out similar research; and/or complimentary provision of SAN can be arranged.

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