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# STRAWBERRY YIELD AND QUALITY RESPONSE TO DIFFERENT FERTILIZER FORMULATIONS

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A field experiment was conducted in 2024 on a private farm located in the Kupiškis region to assess the effects of different fertilizer formulations on the growth, yield, and quality parameters of strawberries. The study involved a review of scientific literature, implementation of a field trial, evaluation of yield performance and fruit quality (based on Brix index), as well as an analysis of potential economic benefits. The experimental design compared two fertilizer formulations: NovaTec Solub, a stabilized nitrogen fertilizer incorporating the nitrification inhibitor DMPP (3,4-dimethylpyrazole phosphate), and a conventional mineral fertilizer. The application of a nitrification inhibitor is known to reduce nitrogen leaching and improve nitrogen use efficiency. The results indicated that NovaTec Solub significantly increased the yield of the 'Asia' strawberry cultivar by 20.4% compared to the conventional treatment. Although the Brix index was slightly higher in strawberries treated with conventional fertilizer (14.08) compared to those fertilized with NovaTec Solub (13.85), the difference was not statistically significant. These findings suggest that stabilized nitrogen fertilizers are effective in enhancing strawberry productivity without negatively affecting fruit quality. Therefore, their use may offer agronomic and economic advantages in commercial berry production systems.

***Keywords:*** *stabilized nitrogen, nitrification inhibitor, Brix index, strawberry yield.*

## INTRODUCTION

The garden strawberry (*Fragaria* × *ananassa* Duch.), a hybrid of the Virginia (*Fragaria virginiana*) and Chilean (*Fragaria chiloensis*) strawberries, was first developed in 18th-century France and soon replaced native European species due to its superior fruit quality (Švirinas, 2025). In Lithuania, strawberries began to be cultivated in the late 18th century and have since become an important berry crop (Švirinas, 2025). Between 2020 and 2023, the strawberry cultivation area and yields in Lithuania showed moderate declines, with production stabilizing at around 2.4 thousand tons in recent years (Lietuvos statistikos departamentas, 2025).

Garden strawberries (*Fragaria* × *ananassa* Duch.) are not only tasty and aromatic but also a highly nutritious fruit, containing vitamins, minerals, dietary fibre, and biologically active compounds beneficial to human health (Skurichinas, Volgareva, 1987; Akimovas ir kt., 2019; Govorova, Govorov, 2024; FitAudit., 2025; Мой здоровый рацион, n. d.). Their high content of vitamin C, organic acids, and anthocyanins supports the immune system, improves digestion, and helps protect cells from aging (Skurichinas, Volgareva, 1987). Available fresh, frozen, or processed year-round, strawberries are an important component of a healthy diet and widely consumed in Lithuania and other countries.

Strawberry productivity, fruit quality, and stress tolerance are strongly influenced by appropriate nutrition at all stages of plant development. Both macroelements (N, P, K, Mg, Ca, S) and microelements (Fe, Zn, B, Mn, Mo, etc.) are required in varying amounts throughout the vegetative cycle to ensure optimal growth and yield (Darnell, Stutte, 2001; Fattahi, Gholami, 2009; Trejo-Téllez, Gómez-Merino, 2014; Better Homes & Gardens, n.d.; Yara, n.d.; Flavoralchemy, n.d.). Nutrient requirements vary depending on the developmental stage. During early vegetation, calcium, phosphorus, and nitrogen are essential for leaf expansion and root system development. Boron, potassium, and magnesium become critical during the budding and flowering stages to support flower formation and ovary development. Fruit size, flavour, and quality are influenced by potassium, calcium, and magnesium availability during fruit development and ripening, while nitrogen, phosphorus, and potassium are required post-harvest to regenerate the plant and form buds for the following season (Darnell, Stutte, 2001; Fattahi, Gholami, 2009; Yara, n.d.; Better Homes & Gardens, n.d.).

Nitrogen is a particularly important nutrient in strawberry cultivation, yet its efficiency depends on the chemical form and application method. Ammonium nitrogen ($NH_4^+$), for example, is well retained in the soil but can be toxic at high concentrations. Nitrate nitrogen ($NO_3^-$) is rapidly absorbed by plant roots, however, it is susceptible to leaching.

Stabilized nitrogen formulations, such as NovaTec Solub with 3,4-dimethylpyrazole phosphate (DMPP), combine the benefits of both forms by slowing the conversion of $NH_4^+$ to $NO_3^-$, reducing nitrogen losses, and supporting higher yields, albeit at a higher cost (Ammonium and Nitrate, n. d.; COMPO Expert, n. d.; International Fertilizer Association, n. d.; Balašovas, 2018). Overall, precise fertilization management, tailored to the plant's developmental stage and nutrient needs, is essential to optimize strawberry growth, fruit quality, and productivity.

The aim of this work is to study the influence of different forms of fertilizers on the growth, yield, and quality of strawberries under Lithuanian farm conditions.

## RESEARCH METHODS

The field experiment was carried out in Plačeniškiai village, Kupiškis district, Lithuania (55.8556° N, 25.1044° E) in 2024, to assess the effects of different fertilizer regimes on the growth, yield, and fruit quality of the strawberry cultivar 'Asia'. This mid-early cultivar is characterized by high productivity, large fruit, and moderate tolerance to both abiotic stress and common strawberry diseases.

The experimental plot covered 800 m² (47 m × 17 m). Prior to planting, the soil was mechanically cultivated, perennial weeds were removed, and a base fertilization with the compound fertilizer "Yara Mila Complex" (20 kg per 0.08 ha, equivalent to 250 kg ha⁻¹) was applied. Agrochemical analyses performed previously (in 2020) indicated a soil pH of 6.3, humus content of 2.62%, and available phosphorus ($P_2O_5$) and potassium ($K_2O$) levels of 145 mg kg⁻¹ and 194 mg kg⁻¹, respectively. These values indicate neutral soil with medium humus and phosphorus levels and high potassium content, suitable for strawberry cultivation.

The experiment used frigo strawberry seedlings (Class A, crown diameter 10-014 mm, usually with two peduncles). Plants were established on low raised beds covered with Pegas Agro black agrotextile film (Czech Republic; 50 g m⁻², 1.2 m width). The agrotextile provided weed control, moisture retention, and pest protection while maintaining soil aeration and water permeability. Planting took place in the second half of August 2023. Seedlings were arranged in two rows per bed with a 30 cm distance between plants and 50 cm between rows. This configuration resulted in a planting density of approximately 6 plants m⁻² (≈ 60,000 plants ha⁻¹). Straw mulch was added between rows to maintain soil moisture and cleanliness of the fruit. Irrigation and fertigation were conducted via a simple drip system consisting of two perforated polyethylene pipes supplying water and dissolved fertilizers.

The fertilization trial was arranged in a randomized block design comprising two treatments:

1) NovaTec Solub 10-5-30+2Mg+TE fertilizer containing the nitrification inhibitor DMPP (3,4-dimethylpyrazole phosphate).

2) The conventional fertilizer with the corresponding composition – 8-11-36+3Mg+TE.

Four replicates per treatment were established on plots of 20 m² (approximately 120 plants per plot). For statistical consistency, data were calculated based on 100 representative plants (≈17 m²).

Fertilization followed four key phenological stages: the beginning of vegetation, flowering, post-flowering, and fruiting. A total of eight fertilizer applications were performed - one at the start of vegetation, one during flowering, two after flowering, and four during fruiting. The application rate of both fertilizers was 20 kg ha$^{-1}$ per fertilization event. Consequently, each plant received a dosage of 0.34 g of fertilizer per application. For the treatment using NovaTec Solub 10-5-30+2 Mg+TE, the total seasonal nutrient delivery per plant amounted to 0.272 g N, 0.136 g $P_2O_5$, and 0.816 g $K_2O$. In comparison, the treatment with conventional fertilizer resulted in a total seasonal delivery of 0.218 g N, 0.299 g $P_2O_5$, and 0.979 g $K_2O$ per plant. All other cultivation measures (weeding, irrigation, pest control, and mulching) were applied equally across treatments.

The following parameters were recorded: total berry yield obtained per hectare (cumulative mass of harvested berries, including marketable and unmarketable fruit); yield of berries (kg) harvested from a 17 m² test plot over individual picking sessions; soluble solids content (Brix).

Soluble solids content (Brix): measured using a hand-held optical refractometer (ATAGO PAL-1, Japan). For Brix analysis, representative samples were collected by randomly selecting marketable berries from different positions within each replicate plot. A composite juice sample was prepared from at least 15 berries per replicate, and measurements were performed in triplicate using a refractometer. A few drops of fresh juice were placed on the prism surface, and readings were recorded according to the optical shadow boundary observed through the eyepiece. The Brix value served as an indicator of fruit sweetness and ripeness.

Meteorological data were obtained from the Keršuliškiai meteorological station (Kupiškis district). Meteorological data between August 2023 and June 2024 indicate substantial fluctuations in air temperature and precipitation compared to the long-term climatic average. The average air temperature (Figure 1) in August 2023 was 21.1°C, which was slightly above the long-term mean (20.6°C).

A gradual decline followed in autumn, reaching 10.1°C in October and 2.2°C in November. During the winter months, the temperature dropped below freezing, with the lowest average observed in January (-4.7°C), about 1.3°C lower than the long-term average (-3.4°C). From February onward, temperatures began to rise steadily, reaching 10.1°C in April and 20.7°C in June 2024, closely aligning with the climatic norm.

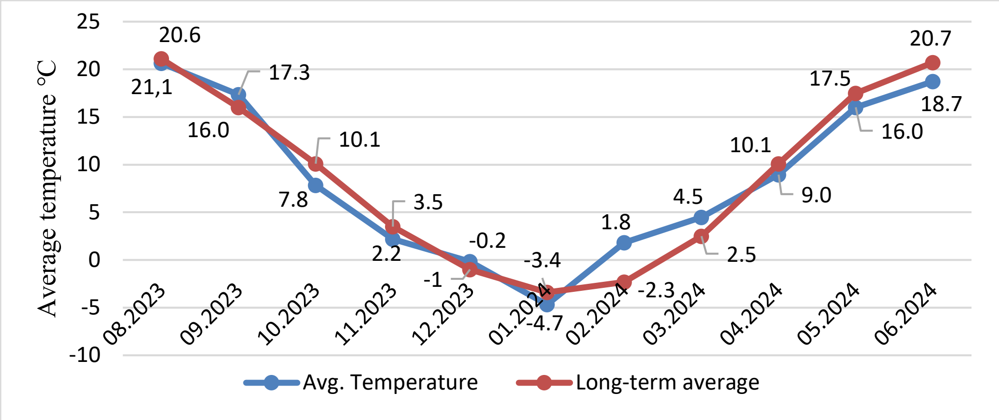


**Figure 1.** Average monthly air temperature and long-term averages in the Kupiškis district during the strawberry growing period.

Precipitation patterns were irregular throughout the experimental period (Figure 2). August 2023 was markedly wetter than average (105.3 mm vs. 61.0 mm), creating favourable soil moisture conditions for strawberry establishment. However, a significant decrease in rainfall occurred in September (11.6 mm vs. 50.8 mm average), which could have slightly stressed young transplants. Rainfall levels increased again in October (77.7 mm) and remained moderate throughout the late autumn and winter months (39-68 mm), ensuring sufficient moisture for root development before dormancy. In spring 2024, precipitation peaked again in April (71.2 mm), exceeding the long-term average by more than twofold, followed by a drier May (26.6 mm) and moderate rainfall in June (68.6 mm).

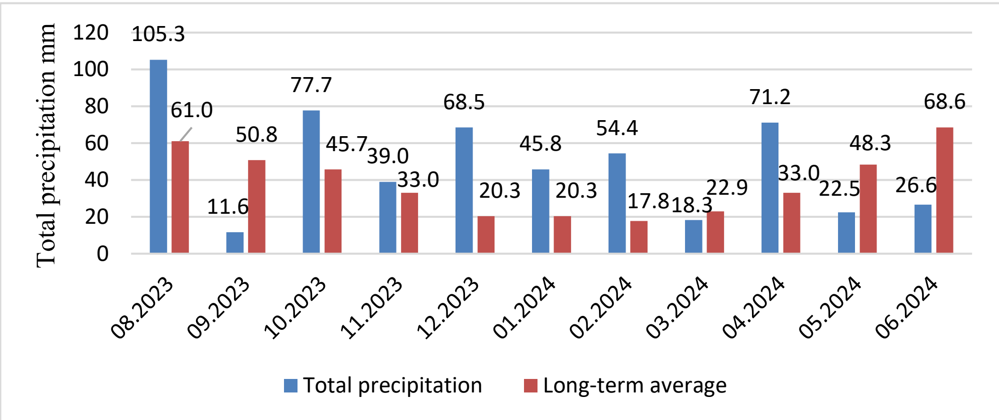


**Figure 2.** Monthly total precipitation and long-term averages in the Kupiškis district during the strawberry growing period.

Overall, the climatic conditions were generally favourable for the establishment and overwintering of the strawberry plants. The warm and moist conditions in August promoted good root development and plant establishment. Despite a brief drought period in September, plants had already developed sufficient root systems to withstand moderate moisture deficits. The winter temperatures, although occasionally dropping below the long-term average, did not pose a significant threat to the overwintering plants due to adequate snow cover and the cultivar's moderate frost tolerance.

In early spring (March - April 2024), increasing temperatures and adequate precipitation stimulated vegetative growth, leaf expansion, and early flower bud initiation. The high rainfall in April improved soil moisture reserves but may have temporarily increased disease pressure. Subsequently, the combination of moderate rainfall and rising temperatures in May and June 2024 created optimal conditions for flowering, fruit set, and berry ripening. Consequently, the overall climatic conditions during the study period supported successful establishment, survival through winter, and productive growth of strawberry cv. 'Asia' under the temperate continental climate of northern Lithuania.

Differences between treatments were evaluated using a one-way analysis of variance (ANOVA) to test the effect of fertilizer type on yield, fruit quality, and other measured traits. When significant differences were detected, Fisher's Least Significant Difference (LSD) test was applied for pairwise comparison of treatment means. Statistical significance was determined at the $p < 0.05$ level. The results were interpreted to assess the efficiency of NovaTec Solub fertilizer in comparison with the conventional fertilization regime, focusing on productivity and fruit quality (Brix index).

## RESEARCH RESULTS AND DISCUSSION

The yield of strawberries (*Fragaria* × *ananassa* cv. 'Asia') was assessed throughout the fruiting period by recording the total weight of berries harvested from a 17 m² test plot under two fertilization treatments: NovaTec Solub (10-5-30+2Mg+TE with DMPP) and conventional fertilizer (8-11-36+3Mg+TE). Eight consecutive harvesting sessions were conducted from June 7 to June 30, 2024, and yields were expressed in kilograms per plot (Figure 3). During the first harvest on June 7, the yield obtained from NovaTec Solub-treated plots was 3.6 kg, while the control plots fertilized with conventional fertilizer produced 4.0 kg. At this early stage of fruiting, the difference (0.4 kg) was statistically insignificant, being well below the minimum significant difference.

By June 10, the productivity of the NovaTec Solub plots increased sharply to 5.8 kg, compared to 4.4 kg in the control. The 1.4 kg difference, although notable, still remained statistically insignificant. Subsequent pickings showed a progressive yield increase in both treatments, with NovaTec Solub consistently producing higher yields. On June 14, yields reached 9.4 kg and 8.6 kg, respectively, again showing a minor but consistent advantage for NovaTec Solub. A statistically significant difference first appeared on June 18, when NovaTec Solub-treated plots yielded 11.6 kg, exceeding the control (9.8 kg) by 1.8 kg. This trend strengthened toward June 21, when the maximum yields were recorded: 13.0 kg for NovaTec Solub and 11.0 kg for the conventional treatment. The difference of 2.0 kg closely matched the significance boundary, indicating a statistically meaningful improvement in yield under NovaTec Solub fertilization. After the peak harvest, yields gradually declined, following the typical fruiting curve of the 'Asia' cultivar.

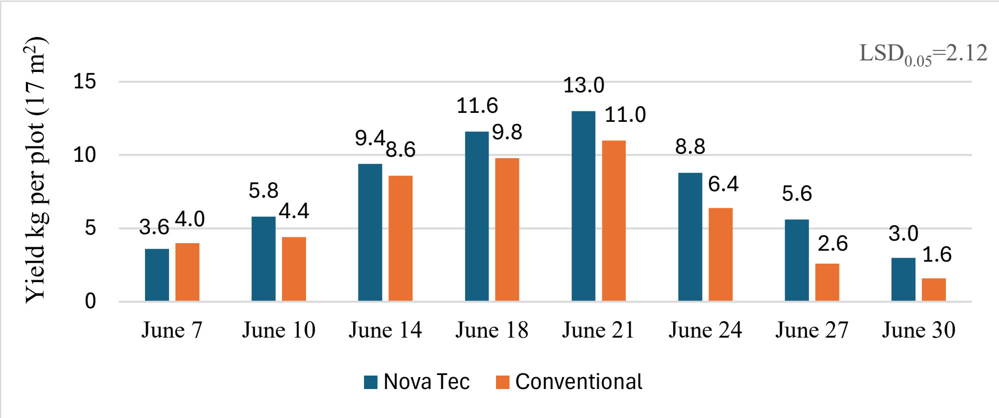


**Figure 3.** Yield of berries (kg) harvested from a 17 m² test plot over individual picking sessions.

On June 24, NovaTec Solub-treated plots still maintained a higher yield (8.8 kg) than the control (6.4 kg), and the difference of 2.4 kg exceeded the least significant difference, confirming statistical significance ($p < 0.05$). In the final harvests - June 27 and June 30 - NovaTec Solub plots produced 5.6 kg and 3.0 kg, respectively, compared to 2.6 kg and 1.6 kg from the control. Both differences (3.0 kg and 1.4 kg) clearly demonstrate a superior and prolonged fruiting performance under NovaTec Solub treatment.

Overall, the data reveal that NovaTec Solub fertilizer ensured a consistently higher and statistically reliable yield compared to conventional fertilization. Although the first two harvests did not differ significantly, from mid-June onward the yield advantage of NovaTec Solub became consistent and significant. The results confirm that the use of NovaTec Solub fertilizer with DMPP enhanced fruit productivity and extended the effective fruiting period of the 'Asia' cultivar, leading to an improved total yield per 17 m² plot.

The analysis of strawberry yield data revealed a clear and statistically confirmed advantage of NovaTec Solub fertilization compared with the conventional nutrient regime. Over the entire harvesting period, plots treated with NovaTec Solub produced a total yield of 35.76 t ha⁻¹, whereas those treated with conventional fertilizer reached 28.47 t ha⁻¹. The yield difference of 7.29 t ha⁻¹, corresponding to a 20.39% increase, demonstrates the consistent superiority of NovaTec Solub throughout the fruiting season (Figure 4).

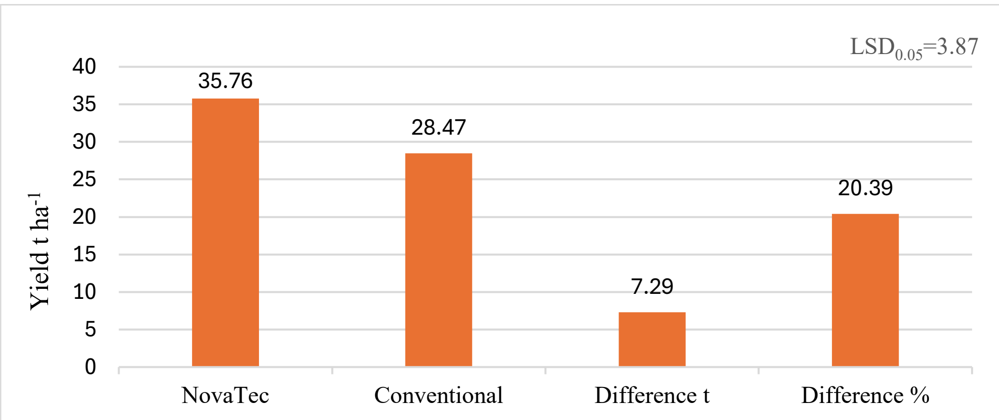


**Figure 4.** The effect of different fertilizers on the yield of 'Asia' strawberries per hectare.

Statistical evaluation using the least significant difference test at the 5% probability level confirmed the reliability of the obtained results. The difference between treatments exceeded the least significant difference, indicating that the yield increase under NovaTec Solub fertilization was statistically significant ($p < 0.05$) and not attributable to random variation.

The higher yield in NovaTec Solub-treated plots can be attributed to several interacting factors. The inclusion of the nitrification inhibitor DMPP in NovaTec Solub fertilizer likely enhanced nitrogen use efficiency by slowing the conversion of ammonium to nitrate, thereby reducing leaching losses and maintaining a stable nitrogen supply throughout the growth and fruiting period. This ensured improved vegetative vigour, balanced canopy development, and more efficient nutrient assimilation during critical phenological phases. In addition, the higher potassium and magnesium content in NovaTec Solub supported photosynthetic activity and carbohydrate translocation, resulting in better fruit filling and higher marketable yield. From an agronomic standpoint, the yield improvement of more than 7 t $ha^{-1}$ is both statistically and economically meaningful, confirming the practical benefits of stabilized nitrogen fertilization under Lithuanian climatic conditions. These findings emphasize that optimized nutrient formulations, particularly those incorporating DMPP-based inhibitors, can substantially enhance the productivity of *Fragaria × ananassa* cv. 'Asia' while promoting more sustainable fertilizer use and potentially reducing environmental nitrogen losses.

The soluble solids content (expressed as the Brix index) of cultivar 'Asia' strawberries was measured at each individual harvest to assess the effect of different fertilizer forms on fruit quality (Table 1). Throughout the harvesting period (7-30 June), the average Brix index values ranged from 12.3 to 15.0 in the NovaTec Solub treatment and from 12.7 to 15.0 in the conventional treatment. The mean soluble solids content for the entire fruiting period was 13.85°Brix for NovaTec Solub and 14.08°Brix for the conventional fertilizer.

At the beginning of the season (7-10 June), both treatments produced similar values (12.3-13.5°Brix for NovaTec Solub and 12.7-12.9°Brix for conventional fertilizer), showing no significant differences in sugar accumulation. The Brix index increased markedly in both treatments from 14 to 21 June, coinciding with the period of peak fruit ripening. The maximum values were recorded on 18 June - 15.0°Brix for NovaTec Solub and 14.9°Brix for conventional fertilization - indicating optimal sugar accumulation under both nutrient regimes.

**Table 1.** Average Brix index values (°Brix) in *Fragaria × ananassa* cv. 'Asia' strawberries during the harvesting period under different fertilizer forms.

| Date | NovaTec Solub | Conventional |
|---|---|---|
| 7 June | 12.3 | 12.7 |
| 10 June | 13.5 | 12.9 |
| 14 June | 14.6 | 14.5 |
| 18 June | 15.0 | 14.9 |
| 21 June | 14.8 | 15.0 |
| 24 June | 13.5 | 14.3 |
| 27 June | 12.3 | 13.7 |
| 30 June | 14.8 | 14.6 |
| Average | 13.85 | 14.08 |
| $LSD_{0.05}$ | 0.77 | |

Subsequent harvests (24-30 June) revealed a slight decline in Brix values as fruiting intensity decreased, a typical trend for late-season harvests when water content in berries tends to increase due to weather and physiological factors. Across all sampling dates, differences between NovaTec Solub and conventional treatments were small, generally within ±0.3°Brix, and did not exceed the minimum statistically significant difference. This statistical assessment indicates that the observed differences in Brix index between fertilizer forms were not significant at the 5% probability level ($p > 0.05$). Therefore, while NovaTec Solub-treated strawberries exhibited slightly lower average soluble solids content (by 0.23°Brix or 1.6%), the variation lies within the range of natural biological variability and cannot be attributed to the fertilization form.

Overall, the results suggest that both fertilizer forms ensured a comparable accumulation of soluble solids in the 'Asia' cultivar. The use of NovaTec Solub, despite primarily enhancing yield performance, did not significantly alter fruit sweetness or total soluble solids content, confirming that fertilizer form had no substantial effect on this quality parameter under the given environmental and agronomic conditions.

## CONCLUSIONS

Fertilization with NovaTec Solub (10-5-30+2Mg+TE with DMPP) significantly increased the yield of *Fragaria × ananassa* cv. 'Asia' compared to the conventional fertilizer (8-11-36+3Mg+TE). The total yield reached 35.76 t $ha^{-1}$, exceeding the control (28.47 t $ha^{-1}$) by 7.29 t $ha^{-1}$ (20.39%), a difference that was statistically significant. Analysis of yield dynamics showed that NovaTec Solub-treated plants produced significantly higher yields from mid-June onward, indicating more stable and prolonged fruiting compared to the conventional treatment.

The Brix index (°Brix) did not differ significantly between treatments - averaging 13.85°Brix for NovaTec Solub and 14.08°Brix for the conventional fertilizer - demonstrating that fertilizer form did not affect fruit sweetness or soluble solids content.

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