

## A preliminary assessment of growth regulators in agricultural: Innovation for sustainable vegetable nutrition

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### Abstract

Agricultural Production today has to deal with different challenges. It has to increment production for a continuously increasing population, reducing the environmental burdens on the natural systems. In conventional agriculture, this is possible through the increase of inputs, especially nutrients, which, however, are responsible for the biggest part of emissions. It becomes more complicated though, adopting sustainable agricultural practices, to improve the quality and the quantity of agricultural production reducing the inputs use.

Plant growth regulators are described in the literature for the significant role in securing crop management of modern agriculture. Therefore, this joint field experiment has been carried out on a pear orchard (*Pyrus communis* L. cv. Abate Fétel) in Emilia Romagna (Italy) by Fondazione Navarra and TIMAC AGRO Italia S.p.A., to test the “less for more” theory which consists in getting more and better agricultural produce using fewer inputs.

Preliminary results of two consecutive years have confirmed our assumption as it was possible to substantially reduce the total fertilisation units applied, improving significantly quantitative and qualitative production indicators (i.e. flower and fruit density, fruit set (%), the average weight of fruits (g) and the total yield (t/ha)). Results have also shown a positive correlation between plant growth regulators and agronomic efficiency of pears.

### Keywords

Pear trees; TIMAC AGRO Italia; growth regulator; sustainable development; plant nutrition

## 1. Introduction

For decades plant nutrition has been under the scrutiny for the concerns of negative externalities generated from fertilisers' use in agriculture which emerged in the late 1960s [1]. Since a clear correlation has been found between plant nutrition, the eutrophication of surface water, the accumulation of nitrate in water bodies, and energy consumption. Even more recently, global studies have warned from unprecedented nitrate contamination of waters [2], which is creating irreversible direct damage to natural ecosystems and human health [3]. Further, the most universal forms of water quality deterioration in the world for the last decades is freshwater eutrophication from phosphorus loss [4,5].

Looking at the glass-half-full, the importance of fertilisers in agriculture has been extensively documented in the literature for over 150 years of research and experiments. The relevance of plant nutrition is fundamental for *i)* a normal growth and reproduction of the crops [6], *ii)* the average crop yield increase, and *iii)* to improve soil fertility [7]. However, the fertilisers' rates have reached the optimum in the developed world, and the new directions are to reduce them. This has been, for instance, one of the European Green Deal recommendations, expressed in the "Farm to fork strategy"<sup>1</sup> with the target to diminish by 2030 nutrients' losses by at least 50% and reduce fertilisers' use by at least 20% [8].

The focus of scientific innovation is currently on crop bio-stimulants to activate plant natural processes, which, according to the documented literature improve nutrient uptake and efficiency, crop quality and yields and build plants' tolerance to abiotic and biotic stressors [9]. A statutory definition of bio-stimulants has been provided in 2018 by the primary agricultural and food policy tool of the United States federal government (the Farm Bill: <https://www.congress.gov/115/bills/hr2/BILLS-115hr2enr.pdf>). This definition is consistent with the one currently proposed by the European Bio-stimulant Industry Council (EBIC) (<http://www.bio-stimulants.eu/>), and in line with the definition under review by the European Union in the context of the revision of the existing EU regulation (EC) No 2003/2003 relating to fertilisers.

The definition sums up all the scientific aspects raised in the literature and describes a plant bio-stimulant as "a substance or micro-organism that, when applied to seeds, plants, or the

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<sup>1</sup> The Farm to Fork Strategy (F2F strategy) is at the heart of the European Green Deal set out in 2019 to make Europe the first climate-neutral continent by 2050. The F2F strategy addresses comprehensively the challenges of sustainable food systems and recognises the inextricable links between healthy people, healthy societies and a healthy planet.

rhizosphere, stimulates natural processes to enhance or benefit nutrient uptake, nutrient efficiency, tolerance to abiotic stress, or crop quality and yield”.

Nevertheless, du Jardin [10] has identified in a review study seven different categories of bio-stimulants including *i)* humic and fulvic acids, *ii)* protein hydrolysates and other N-containing compounds, *iii)* seaweed extracts and botanicals, *iv)* chitosan and other biopolymers, *v)* inorganic compounds, *vi)* beneficial fungi and *vii)* beneficial bacteria. This emerging field of research is very promising and represents one of the fundamental management aspects of agro-systems to reach sustainable agriculture more resilient to climate change and able to feed the increasing population [11].

Therefore, the literature still needs to explore different research aspects related to the different bio-stimulants categories and their use in agriculture, to answer evolving enquiries arising with the technological advances in this field. In this context, this paper proposed to explore the category of seaweed extracts produced by TIMAC AGRO Italia, the Italian holding of the French multinational “Groupe Roullier” a world leader in the field of plant nutrition with the largest private research centre in Europe dedicated to plant physiology and nutrition and investing in these technologies.

The selection of the crop for trial has also its significance because pears constitute one of the major fruits of temperate climates, it is almost grown in the four corners of the world, reaching a total harvested area of 1.5 million hectares in 2018 and over 23.5 million tons of production [12]. The tree belongs to two species, the common pear cultivated mainly in Europe, the Near East, America and Australia and known as the European pear (*Pyrus communis L.*) given its European descendants; and the Nashi pear or Oriental pear (*Pyrus pyrifolia*) widely grown in Asia.

## 2. Material and Methods

The experiment was carried out in Emilia Romagna (Italy) on *Abate Fetel* orchard for the relevance of this cultivar in Italy, which happens to be the main producer of Pears in Europe [13] and the third world producer in terms of area harvest and second after China in terms of total production (**Table 1a**).

Despite the identified pear cultivars have superated 3,000 worldwide [14], in Italy, *Abate Fetel* (synonym *Abbé Fetel*) with other three cultivars (*Conference*, *Beurré Bosc*, *Doyenne du Comice*), are the major cultivars commercially grown and producing more than 70% of the total annual production [15]. Further, the selection of Emilia Romagna has local importance given that this region is the first ranked in terms of harvest area, the production and the average size of fruit trees farms (**Table 1b**).

**Table 1.** Pears cultivation and production in the top 3 countries and the total world and the top 5 Italian regions and farm size in Italy.

1a: FAOSTAT [12]	Area Harvested		Production	
	(ha)	(%)	(Tons)	(%)
China	937,642	2.1	16,196,649	68.2
India	44,000	3.2	318,000	1.3
Italy	29,616	67.9	716,821	3.0
World	1,381,925	100	23,733,769	100
1b: Istat [16]	Area Harvested		Number of Farms	
	(ha)	(%)	(N°)	(%)
Emilia Romagna (EMR)	67,454.3	15.9	18,355	7.8
Campania (CAM)	58,836.7	13.9	32,133	13.6
Sicily (SIC)	54,295.5	12.8	36,055	15.3
Piedmont (PIE)	43,673.3	10.3	20,168	8.5
Lazio (LAZ)	36,318.8	8.6	15,323	6.5
Sum of top 5 regions	<b>260,578.5</b>	<b>61.4</b>	<b>122,034</b>	<b>51.7</b>
Other regions	<b>163,725</b>	<b>38.6</b>	<b>114,206</b>	<b>48.3</b>
Total Italian fruit farms	<b>424,303.5</b>	<b>100</b>	<b>236,240</b>	<b>100</b>
Average Italian fruit farm size	<b>1.8 ha</b>			
Average fruit farm size in EMR	<b>3.7 ha</b>			
Farm size	Area Harvested		Number of Farms	
	(ha)	(%)	(N°)	(%)
Small farm (< 10 ha)	222,270.4	52.4	201,324	85.2
Medium farm (10-50 ha)	150,171.9	35.4	30,674	13.0
Large farm (>50 ha)	51,861.5	12.2	4,242	1.8
Total Italian fruit farms	<b>424,303.8</b>	<b>100</b>	<b>236,240</b>	<b>100</b>

## 2.1. Case study

The experiment took place at the experimental field of “Navarra Foundation”, a reference in agricultural knowledge for the Navarra agricultural technical institute and all farmers of the North-East of Italy, given its contribution in the development of the agro-food sector of the region through research, experiments, innovation and knowledge transfer.

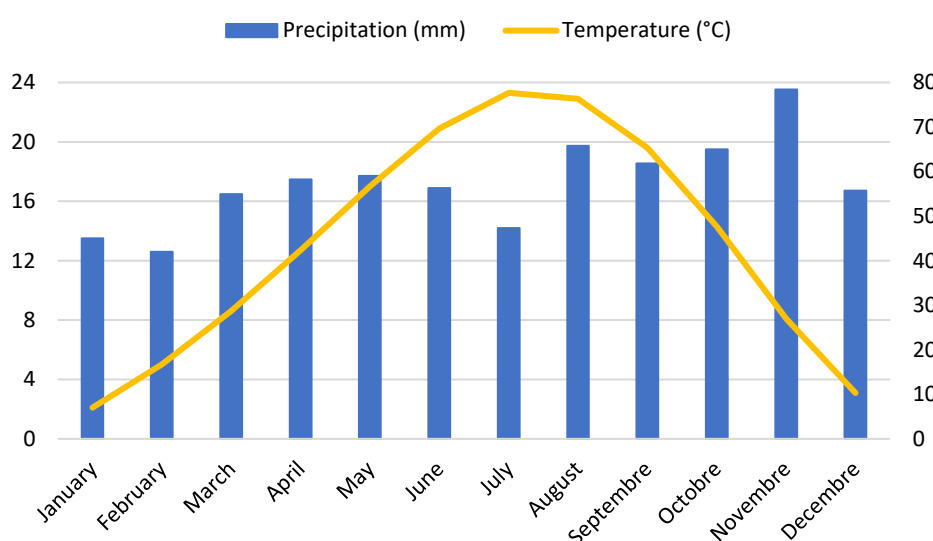
The experimental field has a total area of  $\approx 2.5$  ha similar to the average size of fruit trees farms in the area and is located in Ferrara (**Table 2**) characterised by a warm and temperate climate classified as Cfa by the Köppen-Geiger system. The historic precipitation and temperature data

measured in a weather station in Ferrara (**Table 2**) between 1961 and 1990 revealed a yearly average temperature of 13.1°C and rainfall around 689.5 mm [17], with considerable rain at high temperatures in the driest months (**Figure 1**).

**Table 2.** Geospatial coordinates of the experimental field and weather station of reference.

Location	Latitude	Longitude	Altitude
Experimental Field	44.857 N	11.653 E	5 m
Weather Station	44.861 N	11.656 E	4 m

*Source: [17,18].*



**Figure 1:** Historic average of precipitation and temperature in Ferrara (1961-1990) (After [17]).

The trials took place in 2018-19 for two consecutive seasons on a V-shaped orchard system planted in 2005 using 3.8 m spacing between rows and a variable in-row spacing of 0.5 m, with a tree density of 5,263 trees per hectare. The orchard was evenly irrigated with a drip system without any variation between the rows and it is covered with a black anti-hail netting system.

Soil structure is, according to the classification system of the united states department of agriculture (USDA), silty clay loam, and silt clay following the international soil sciences society (ISS). The general composition of this soil is about 60% silt, 30% clay and 10% sand and it presents a low compaction risk. Soil tests have been carried before and during the experiment to guide the definition of the annual fertilisation programmes.

The fertilisation programme has been divided into three different treatments. The control which was grown without any fertilisation, the conventional treatment (CF) which represents an empirical nutritional treatment conceived from the available products in the region (to simulate a conventional nutritional programme), and the TIMAC AGRO treatment (TIMAC) corresponding

to a programme based on cutting-edge technologies created to reduce the environmental burdens of fertilisers, increase the financial account of the farm and improve farms well-being. The total fertilisation units per hectare of each treatment have been reported in the following treatment (**Table 3**). A supplement of complexed seaweed-based nutrients has been added to the TIMAC treatment (40 L ha<sup>-1</sup>) through different concentrations of three different technologies (Fertiactyl®, NMX® and Seactiv®) registered in European Patent Office (EPO) under the following numbers: EP0609168, EP1147706 and EP0855375.

**Table 3.** Fertilisation units (FU) applied per treatment and hectare in 2018 and 2019 seasons.

Type	Element	2018 – FU ha <sup>-1</sup>			2019 – FU ha <sup>-1</sup>		
		CF	TIMAC	$\Delta(TIMAC - CF)$	CF	TIMAC	$\Delta(TIMAC - CF)$
Macro-Nutrients	Nitrogen (N)	205.1	141.3	<b>-63.8</b>	174.9	120.7	<b>-54.2</b>
	Phosphorus (P <sub>2</sub> O <sub>5</sub> )	184.4	79.0	<b>-105.4</b>	103.1	77.6	<b>-25.5</b>
	Potassium (K <sub>2</sub> O)	292.7	145.1	<b>-147.6</b>	246.0	140.8	<b>-105.2</b>
	Total Macro-Nutrient	682.2	365.4	<b>-316.8</b>	524	339.1	<b>-184.9</b>
Meso-Nutrients	Calcium (CaO)	42.5	46.4	<b>+3.9</b>	4.8	43.2	<b>+38.4</b>
	Magnesium (MgO)	21.6	24.1	<b>+2.5</b>	3.0	35.8	<b>+35.8</b>
	Sulphur (SO <sub>3</sub> )	109	200.2	<b>+91.2</b>	49.5	197.6	<b>+148.1</b>
	Total Macro-Nutrient	173.1	270.7	<b>+97.7</b>	57.3	276.6	<b>+219.3</b>
Micro-Nutrients	Boron (B)	0.45	0.88	<b>+0.43</b>	0	1.45	<b>+1.45</b>
	Copper (Cu)	0.43	0.06	<b>-0.37</b>	0	0.05	<b>+0.05</b>
	Iron (Fe)	5.83	3.90	<b>-1.93</b>	2.25	1.50	<b>-0.75</b>
	Manganese (Mn)	0.24	0	<b>-0.24</b>	0.03	0.07	<b>+0.04</b>
	Molybdenum (Mo)	0.01	0.04	<b>+0.03</b>	0	0.30	<b>+0.3</b>
	Zinc (Zn)	0.31	0.10	<b>-0.21</b>	0.02	0.11	<b>+0.09</b>
	Total Micro-Nutrient	7.26	4.98	<b>-2.28</b>	2.30	3.48	<b>+1.18</b>
OM	Total Organic Matter	43.8	44.4	<b>+0.6</b>	48.7	41.2	<b>-7.5</b>

## 2.2. Statistical analysis

The adopted experimental design was the randomised block design to minimise the effects of systematic errors. This design consisted of dividing the experimental block into three fertilisation treatments randomly selected within the block, with two replicated each made of 5 trees for each treatment. In total 60 trees were used for data collection and statistical analysis to determine whether mean scores differed significantly across the treatments. The measurements performed are divided into three pillars as follows:

- Flower density;
- Fruit density;
- Fruit Set;
- Total harvest (t ha<sup>-1</sup>)

➤ Average fruit weight (g)

➤ Agronomic efficiency

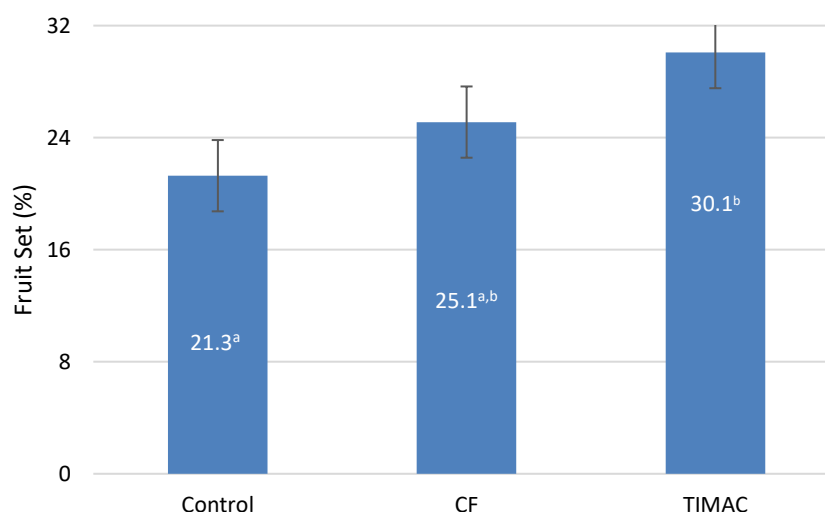
$$AE (kg/kg) = \frac{Yield_{fertilised} (kg/ha) - Yield_{not\ fertilised} (kg/ha)}{N\ Applied (kg/ha)}$$

The field data collected have been statistically examined adopting the analysis of variance (one-way ANOVA) with a statistical probability ( $p - value \leq 0.05$ ), and Tukey's HSD test which is a single-step multiple comparison procedure to find significantly different means.

### 3. Results

Plants within a population often vary in the numbers of open flowers (flower density =  $FBT = \text{Number of Floral Buds per Tree}$ ) and the number of fruits (fruit density =  $NFT = \text{Number of Fruit per Tree}$ ). The correlation between those two indicators is calculated by the fruit set, a ratio defined as the transition from flower to young fruit (Fruit Set =  $FS = (NFT/FBT) \times 100$ ). These quantitative indicators, in the development process of any plant, are correlated to the rate of pollination [19] and they determine the final yield quantities (or the total harvest).

Field data for two consecutive years have demonstrated an increase of all quantitative indicators under the TIMAC treatment compared to the conventional treatment and the control which generated the highest harvest for TIMAC treatment (**Figure 2**). Even though the numerical difference is considerable, the statistical significance is present only between the Control and TIMAC treatment. Complete statistical results are listed in a final table (**Table 4**).



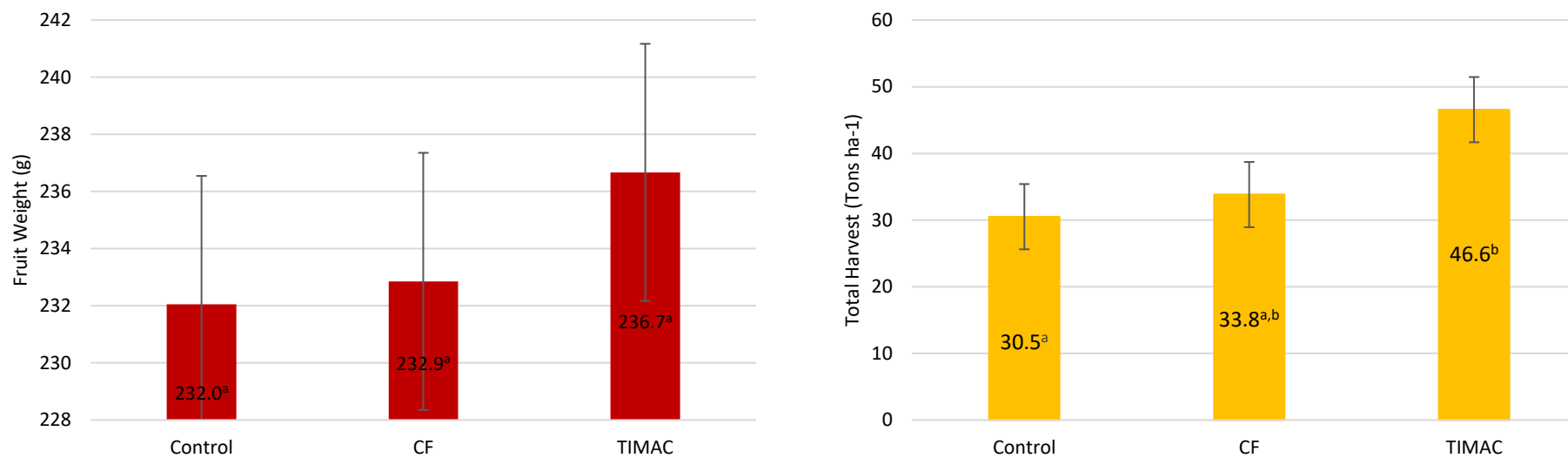
**Figure 2:** The averaged results (2018-2019) of Fruit Set for the three treatments.

However, high plant fertility would negatively affect the quality of the harvest which would require, in conventional agriculture, flower removal intervention to boost the harvest quality [20-

22]. The role of plant regulators has been retained fundamental at this growth stage of plants to control fruit set [23] and to boost simultaneously the quantity and the quality of yields [24].

While the average fruit weight of different pear cultivars could vary according to the genetic characteristics [25], within the same variety, the fruit fresh weight is considered one of the most important quality indicators [26] which determines the value of the harvest on the market. The averaged results of this experiment confirm the results of An et al [23] and Bons and Kaur [24] and the next figure shows the qualitative and quantitative improvement of yields in the TIMAC treatment (**Figure 3**).





**Figure 3:** Improvement of fruit weight (to the left) and total harvest (to the right) under TIMAC treatment.

**Table 4.** Statistical results of the selected indicators.

Indicator	Treatment	First Year – 2018			Second Year – 2019			Average		
		Mean	Std Dev.	Variance	Mean	Std Dev.	Variance	Mean	Std Dev.	Variance
Flower Density	Control	223.5 <sup>a</sup>	25.4	681.1	61.0 <sup>a</sup>	33.9	1211.0	142.2 <sup>a</sup>	86.6	7696.8
	CF	219.4 <sup>a</sup>	28.7	865.8	53.1 <sup>a</sup>	28.3	844.6	136.3 <sup>a, b</sup>	87.9	7924.5
	TIMAC	223.6 <sup>a</sup>	27.7	807.6	74.0 <sup>a</sup>	36.3	1384.2	148.8 <sup>b</sup>	81.4	6802.5
Fruit Density	Control	38.2 <sup>a</sup>	10.5	115.4	11.1 <sup>a</sup>	6.1	39.8	24.6 <sup>a</sup>	16.0	263.2
	CF	42.4 <sup>a, b</sup>	18.1	343.2	13.9 <sup>a</sup>	9.4	93.7	28.1 <sup>a, b</sup>	20.2	420.4
	TIMAC	50.4 <sup>b</sup>	17.1	308.4	25.1 <sup>b</sup>	11.4	136.2	37.8 <sup>b</sup>	19.3	380.7
Fruit Set	Control	17.4 <sup>a</sup>	5.3	29.4	25.2 <sup>a</sup>	22.9	551.6	21.3 <sup>a</sup>	17.1	298.7
	CF	20.1 <sup>a</sup>	10.2	109.5	30.1 <sup>a</sup>	17.7	328.1	25.1 <sup>a, b</sup>	15.3	238.8
	TIMAC	22.3 <sup>a</sup>	6.2	40.9	37.9 <sup>a</sup>	18.7	368.0	30.1 <sup>b</sup>	16.0	261.3
Fruit Weight	Control	238.9 <sup>a</sup>	29.0	882.9	225.2 <sup>a</sup>	25.5	684.6	232.0 <sup>a</sup>	28.1	812.3
	CF	237.1 <sup>a</sup>	31.8	1064.4	228.6 <sup>a</sup>	24.7	643.9	232.9 <sup>a</sup>	28.8	850.6
	TIMAC	242.7 <sup>a</sup>	24.5	633.8	230.6 <sup>a</sup>	30.1	952.4	236.7 <sup>a</sup>	28.1	810.2
Total Harvest	Control	47.5 <sup>a</sup>	13.1	180.7	13.5 <sup>a</sup>	8.1	69.7	30.5 <sup>a</sup>	20.2	417.4
	CF	51.6 <sup>a, b</sup>	19.8	413.5	16.1 <sup>a</sup>	9.9	104.0	33.8 <sup>a</sup>	23.7	576.0
	TIMAC	63.3 <sup>b</sup>	19.1	384.6	29.8 <sup>b</sup>	12.7	169.3	46.6 <sup>b</sup>	23.3	557.5

In the table, statistically significant means of different indicators are followed by different letters.

Nutrients agronomic efficiency (AE in kg kg<sup>-1</sup>) measures the technical performance of a crop. Specifically, it estimates productivity improvement gained by the use of nutrient input. First, it has been used to evaluate nitrogen performance [27,28], to improve the environmental and economic performance of agriculture, after that it has been extended to include the performance of phosphorus nutrition [29], to reach a broader meaning and agronomic efficiency correlated inputs use to agro-system performance as an indicator for a transition to sustainable agriculture [30].

In this study, we calculated nitrogen efficiency, phosphorus efficiency and total nutrients' efficiency for the conventional fertilisation treatment and TIMAC treatment (**Table 5**). Results showed that the efficiency of TIMAC treatment varied between 5.18 and 9.37 time higher compared to the conventional treatment (CF).

**Table 5.** Nutrients' agronomic efficiency of different treatments during the experimental years.

Year	Treatment	$AE_{(N)}$	$AE_{(P_2O_5)}$	$AE_{(Total)}$
1 <sup>st</sup> Year (2018)	CF	20.1	22.3	4.8
	TIMAC	112.1	200.4	24.7
	<b>TIMAC/CF</b>	<b>5.58</b>	<b>8.98</b>	<b>5.18</b>
2 <sup>nd</sup> Year (2019)	CF	14.4	24.4	4.3
	TIMAC	134.9	209.8	26.3
	<b>TIMAC/CF</b>	<b>9.37</b>	<b>8.59</b>	<b>6.10</b>
Average Year (2018-2019)	CF	17.5	23.1	4.6
	TIMAC	122.6	205.1	25.5
	<b>TIMAC/CF</b>	<b>7.02</b>	<b>8.89</b>	<b>5.56</b>

#### 4. Conclusion

The averaged results over two consecutive years of experiments have shown the role of plant growth regulators in the reduction of fertilisation units (FU) around 13%, which is an encouraging outcome towards the reduction of fertilisers according to the European "Farm to fork strategy" . Results have also revealed a substantial reduction in P<sub>2</sub>O<sub>5</sub> use (over 45%) which is a significant result impacting the AE of phosphorus, and participating in the global efforts to reduce and/or substitute the use of phosphate rock, a mineral fundamental for food security expected to end in a short lifetime [31,32].

The field experiment has confirmed the reviewed literature in Bons and Kaur [24] which assessed the positive correlation between plant growth regulators, quality and quantity of harvests, as the TIMAC treatment has improved both quality and quantity of the pears. Therefore, these results

have disproved though results of Dicenta et al [33], which could not find a correlation between fruit set and the total harvest.

Some questions that the research has raised and some future recommendations are mainly related to the importance of the balanced nutrition programme for sustainable management of crops. This has been defined by Liebig's law of the minimum which is a fundamental principle in plant nutrition, this research has partially demonstrated the importance of this law on the overall agronomic efficiency of the crop (AE has not been assessed in this study). Furthermore, it would be recommended to follow the framework suggested by El Chami et al [11] who proposed a methodology to reach sustainable agro-systems based on a life cycle study [34]. Therefore, future studies will be intensified and will address these questions and will implement the methodology suggested by El Chami et al [11], towards the European "Farm to fork strategy" and the United Nations sustainable development goals.

## 5. Acknowledgement

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## 6. Author Contributions

The main author has contributed to the conception, realisation and publication of the research, and has performed the statistical analysis, and the co-author (corresponding author) has set-up the experiment and followed field works and data collection.

## 7. Conflict of Interest Statement

The authors declare no conflict of interest.

## 8. References

1. Viets, F.G.; Lunin, J. The environmental impact of fertilizers. *Crit. Rev. Env. Control* **1975**, *5* (4): 423-453. doi:10.1080/10643387509381630
2. Zhou, Z. *A global assessment of nitrate contamination in groundwater*. Internship report. Wageningen University, The Netherlands (2015).
3. Ward, M.H.; Jones, R.R.; Brender, J.D.; de Kok, T.M.; Weyer, P.J.; Nolan, B.T.; Villaneuva, C.M.; van Breda, S.G. Drinking Water Nitrate and Human Health: An Updated Review. *Int. J. Environ. Res. Public Health* **2018**, *15* (7): 1557. doi:10.3390/ijerph15071557

4. MacDonald, G.K.; Bennett, E.M.; Potter, P.A.; Ramankutty, N. *Agronomic phosphorus imbalances across the world's croplands*. *P. Natl Acad. Sci. USA* **2011**, *108* (7): 3086-3091. doi:10.1073/pnas.1010808108
5. Sharpley, A.N.; McDowell, R.W.; Kleinman, P.J.A. Phosphorus loss from land to water: integrating agricultural and environmental management. *Plant and Soil* **2001**, *237*: 287-307. doi:10.1023/A:1013335814593
6. Barker, A.V.; Pilbeam, D.J. Introduction. In: *Handbook of plant nutrition*, Barker AV and Pilbeam DJ (Eds.). 2<sup>nd</sup> Edition, CRC Press, Florida (USA) (**2007**): 3-18.
7. Dong, W.; Zhang, X.; Wang, H.; Dai, X.; Sun, X.; Qiu, W.; Yang, F. Effect of Different Fertilizer Application on the Soil Fertility of Paddy Soils in Red Soil Region of Southern China. *PLoS ONE* **7** (9) **2012**: e44504. doi:10.1371/journal.pone.0044504
8. EU. *Farm to fork strategy: For a fair, healthy and environmentally-friendly food system*. Brussels (Belgium) (2020). 22 p. Available Online: [https://ec.europa.eu/food/sites/food/files/safety/docs/f2f\\_action-plan\\_2020\\_strategy\\_info\\_en.pdf](https://ec.europa.eu/food/sites/food/files/safety/docs/f2f_action-plan_2020_strategy_info_en.pdf) (Accessed in June 2020).
9. Drobek, M.; Fraç, M.; Cybulska, J. Plant Bio-stimulants: Importance of the Quality and Yield of Horticultural Crops and the Improvement of Plant Tolerance to Abiotic Stress – A Review. *Agronomy* **2019**, *9*: 335; doi:10.3390/agronomy9060335
10. du Jardin, P. Plant bio-stimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae* **2015**, *196*: 3-14. doi:10.1016/j.scienta.2015.09.021
11. El Chami, D.; Daccache, A.; El Moujabber, M. How can sustainable agriculture increase climate resilience? A systematic review. *Sustainability (Basel)* **2020**, *12* (8): 3119. doi:10.3390/su12083119
12. FAOSTAT. *Crop production data*. The United Nations Food and Agricultural Organisation (FAO), Rome (Italy) (2020). Available Online: <http://www.fao.org/faostat/en/#data> (Accessed in June 2020).
13. Eurostat. *Database – Agricultural production*. European Statistics (Eurostat), Brussels (Belgium) (2020). Available Online: <https://ec.europa.eu/eurostat/data/database> (Accessed in June 2020).
14. Elzebroek, A.T.G.; Wind, K. Edible fruits and nuts. In: *Elzebroek ATG and Wind K (Eds.), Guide to Cultivated Plants*. Wallingford: CAB International, Oxford (UK) and Massachusetts (USA) (2008): 25-131.
15. Eccher, T.; Pontiroli, R. Old pear varieties in Northern Italy. *Acta Horticulturae* **2005**, *671*: 243-246. doi:10.17660/actahortic.2005.671.34
16. Istat. The 2010 agricultural census. The National Institute of Statistics (Istat), Rome (Italy) (2020). Available Online: <https://www.istat.it/it/censimenti-permanenti/censimenti-precedenti/agricoltura/agricoltura-2010> (Accessed in June 2020).

17. Harris, I.C.; Jones, P.D. *CRU TS4.01: Climatic Research Unit (CRU) Time-Series (TS) version 4.01 of high-resolution gridded data of month-by-month variation in climate (Jan. 1901-Dec. 2016)*. University of East Anglia, Climatic Research Unit, Centre for Environmental Data Analysis, Norwich (UK) (2017). doi:10.5285/58a8802721c94c66ae45c3baa4d814d0
18. Google Earth. *Navarra Foundation and Weather station in Ferrara (44.857 N, 11.653 E and 44.861 N, 11.656 E)*. Google Earth Pro. v. 7.3, 3 D map, building data layer (2020). Available Online: <http://www.google.com/earth/index.html> (Accessed in June 2020).
19. Essenberg, C.J. Explaining Variation in the Effect of Floral Density on Pollinator Visitation. *Am. Nat.* **2012**, *180* (2): 153-166. doi:10.1086/666610
20. Balkic, R.; Gunes, E.; Altinkaya, L.; Gubbuk, H. Effect of male bud flower removal on yield and quality of 'Dwarf Cavendish' banana. *Acta Hortic.* **2016**, *1139*: 587-590 doi: 10.17660/ActaHortic.2016.1139.101
21. Dong, H.; Zhang, D.; Tang, W.; Li, W.; Li, Z. Effects of planting system, plant density and flower removal on yield and quality of hybrid seed in cotton. *Field Crop. Res.* **2005**, *93* (1): 74-84. doi:10.1016/j.fcr.2004.09.010
22. Dugaard, H. The effect of flower removal on the yield and vegetative growth of A+ frigo plants of strawberry (*Fragaria x ananassa* Duch). *Sci. Hortic.-Amsterdam* **1999**, *82* (1-2): 153-157. doi:10.1016/s0304-4238(99)00044-8
23. An, J.; Althiab Almasaud, R.; Bouzayen, M.; Zouine, M.; Chervin, C. Auxin and ethylene regulation of fruit set. *Plant Sci.* **2020**, *292*: 110381. doi:10.1016/j.plantsci.2019.110381
24. Bons, H.K.; Kaur, M. Role of plant growth regulators in improving fruit set, quality and yield of fruit crops: a review. *J. Hortic. Sci. Biotech.* **2019**, *95* (2): 137-146. doi:10.1080/14620316.2019.1660591
25. Lāce, B.; Lācis, G.; Blukmanis, M. Average fruit weight variability of Pear cultivars under growing conditions of Latvia. *Acta Hortic.* **2015**, *1094*: 189-195 doi:10.17660/ActaHortic.2015.1094.24
26. Zhang, C.; Tanabe, K.; Wang, S.; Tamura, F.; Yoshida, A.; Matsumoto, K. The Impact of Cell Division and Cell Enlargement on the Evolution of Fruit Size in *Pyrus pyrifolia*. *Ann. Bot.-London* **2006**, *98* (3): 537-543. doi:10.1093/aob/mcl144
27. Craswell, E.T.; Godwin, D.C. The efficiency of nitrogen fertilisers applied to cereals in different climates. *Adv. Plant. Nutr.* **1984**, *1*: 1-55.
28. Novoa, R.; Loomis, R.S. Nitrogen and plant production. *Plant and Soil* **1981**, *58*: 177-204. doi:10.1007/BF02180053
29. Casanova, E.F. Agronomic evaluation of fertilisers with special reference to natural and modified phosphate rock. *Fertil. Res.* **1995**, *41*: 211-218. doi:10.1007/BF00748310
30. De Koeijer, T.J. *Efficiency improvement for a sustainable agriculture: The integration of agronomic and farm economics approaches*. Thesis Wageningen University, Wageningen, The Netherlands, (2002). 143 p.

31. Shepherd, J.G.; Kleemann, R.; Bahri-Esfahani, J.; Hudek, L.; Suriyagoda, L.; Vandamme, E.; van Dijk, K.C. The future of phosphorus in our hands. *Nutr. Cycl. Agroecosyst.* **2016**, *104*: 281-287. doi:10.1007/s10705-015-9742-1
32. Herring, J.R.; Fantel, R.J. Phosphate rock demand into the next century: Impact on world food supply. *Nat. Resour. Res.* **1993**, *2*: 226-246. doi:10.1007/BF02257917
33. Dicenta, F.; Ortega, E.; Egea, J. Influence of flower density on fruit set rate and production in almond. *Acta Hortic.* **2006**, *726*: 307-310. doi:10.17660/ActaHortic.2006.726.49
34. El Chami, D.; Daccache, A. Assessing sustainability of winter wheat production under climate change scenarios in a humid climate – An integrated modelling framework. *Agr. Syst.* **2015**, *140*: 19-25. doi:10.1016/j.agry.2015.08.008