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Assessment of Utilization of Sheep Wool Pellets as Organic Fertilizer and Soil Amendment in Processing Tomato and Broccoli

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Abstract: *FloraPell®* is a new organic fertilizer, made fromlow grade coarse grease wool with a mineral content of 10-12% Total Nitrogen and 4-6% Potassium, it is a 100% renewable fertilizer, manufactured by an environmentally friendly process. The objective of this work was to evaluate the effect of floraPell as soil amendment and organic fertilizer in two different field-grown vegetable crops, processing tomato and broccoli. It was demonstrated that the floraPell application as organic fertilizer at the highest doses allowed obtain the highest yields, as much for processing tomato as for broccoli crops under organic farming growing conditions. However, it seems that the quality parameters analysed in the final product, tomato fruits and broccoli heads, were not influenced by fertilising treatments evaluated. Regarding the influence of floraPell as soil amendment, based on the obtained results, the soil characteristics evolution over the trial did not varied with the different treatments applied, as it was very similar among them and even to the control treatment. For both crops, the soil characteristics evolution followed the same trend, except for the organic matter content, which maintained at the same level in processing tomato trial, while decreased slightly at the end of the trial for broccoli. The results suggest that floraPell can be used successfully as alternative biofertilizer, at a doses of 2000 kg/ha (200 N) for both crops, processing tomato and broccoli, making sure a profitable yield for the farmers, in a sustainable and environmental friendly way.

Key words: organic fertilizer, wool pellets, soil amendment, processing tomato, broccoli

1. Introduction

FloraPell® (floraPell) is a new organic fertilizer, made from low grade coarse grease wool or woollen fleeces, to transform them to a high value organic fertilizer and soil amendment. The mineral content of floraPell is 10-12% Total Nitrogen and 4-6% Potassium. The main advantages of this new fertilizer are that it has no extraneous additives or chemicals; it is optimal for vegetables, fruits, ornamental shrubs and trees; one application per season is enough; it is a very good water reservoir, able to absorb water up to 3.5 times of its weight; it provokes soil loosening by swelling effect; the nutrients delivery is continuous and keeps the ground moisture; its pH value is aprox.8.8, so it could be a remedy against over acidification of the soil. Apart from that, it is cool and dry storable at least for 2 years, and in soil, sheep wool pellets will be completely biodegraded. FloraPell is indeed, a 100% renewable fertilizer, manufactured by an environmentally friendly process. This new organic fertilizer corresponds to the European fertilizer regulations.

The wool production worldwide in 2011 was 1.985.797 millions of tonnes, being produced in Europe the 13.4% of this sheep wool. Historically, sheep husbandry was a multipurpose rural activity. Sheep give meat, milk and wool. Sheep can graze over a wide range of mountains, hills or marginal ground,

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they protect the landscape and keep the country open, very economically and environmental friendly. However, with the increasing production of fabrics from artificial fibres and from others natural fibres such as cotton and flax, and a high increase of imported raw wool from Australia and Africa resulted in low demands for coarse wool in Europe. In the last years, sheep shearing was sometimes only an animal welfare activity with no profit for the farmer. Consequently, the development of new products like floraPell sheep wool fertilizer pellets from raw coarse or dirty wool might led to a win-win scenario for both, sheep farmers and for the transferring companies.

The use of waste or by-products as nutrient sources for crop plants has a long history. However, there are some widely available waste products, that have not yet been utilized and that may have potential value as nutrient sources for crops. Examples include sheep wool-waste generated during the process of cleaning raw wool [1]. Sometimes due to price fluctuations, wool production may become uneconomical. Landfilling or surface disposing of the excess or low-grade wool is environmental concern [2]. Hydrolysed wool has been tried as fertilizer source for plants [3] or as binding agent for heavy metals [4]. Zheljazkov et al. (2005, 2008) has demonstrated that uncomposted wool could be used as plant nutrient source, thus may offer an alternative nutrient source for crops to farmers and divert this material from waste sites [5, 6]. Being a N-rich source, wool has been used as feedstock for composting [7-9]. Composted wool has been used as a N source for crop plants such as chickpea and wheat [10, 11].

The organic fertilizers are those whose nutrients are included in organic materials, of animal, vegetal or another natural origin (RD506/2013). They are composed of compounds in which the main nutrients are chemically connected or are part of organic matrix. The real interest in organic fertilizers stems from providing organic matter have shown to increase soil biological activity and biodiversity and associated mineralization capacity of the soil [12], to suppress diseases [13] and induce biochemical pathways in crops involved in pathogen defence and stress tolerance [14]. On top of that, organic matter enhances the physic characteristics of the soil, such as the porosity, water retention, permeability, and encourages soil microorganisms, which, at the same time, eases the transformation of soil compounds into available nutrients for crops. Thus, organic matter gives rise to a higher effectiveness of mineral nutrients up taking [15]. Apart from that, organic amendments provide organic matter too, although its main objective is not the nutrients supplying, comparing with organic fertilizers, but the improvement of physical, chemical and biological soil properties (RD506/2013). The organic fertilizers market is increasing these days. The growth of the organic farming worldwide, around 40 million hectares, rises noticeably these kinds of fertilizers trade. As a result, it is the sector with the best future and expectations within the fertilizers market. Along with organic farming, organic fertilizers are also suitable for sustainable agriculture, integrated production and conventional agriculture systems [15].

Spain is the fourth largest producer of processing tomato in the world, behind USA (California), China and Italy. About 70% of the national production is harvested in the Guadiana River Basin in Extremadura, Western Spain [16]. Yields average 80 t/ha fresh weight while best fields and farmers achieve 100 t/ha [17]. Processing tomato is one of the main crops in Extremadura, where 25000 has are cultivated, obtaining approximately 1.8 million tonnes [18]. Tomato fruits are processed by regional factories, which generate mainly tomato paste, but also powdered tomato and tomato-flakes. Quality standards fall within a wide range depending on processing industry politics, end use of goods, cropping years, annual production and most importantly market conditions. In Spain, such quality standards are often agreed between processing industries and grower associations for each cropping year [19].

Over the last years in Extremadura (Spain), the broccoli cultivated area has increased. In 2013 the cultivated area reached 1747 hectares, with a total production of 21617 tonnes of broccoli heads. Hence, broccoli has become the second most important vegetable grown in Extremadura, after processing tomato. Broccoli has been labelled as the highest nutritional value vegetable, due to its composition in some phytochemical compounds, such as glucosinolates and isothiocyanates, with potential effects on preventing from several types of cancer and others illnesses [20]. For this reason the broccoli consume has increased recently.

The objective of this work was to evaluate the effect of floraPell as soil amendment and organic fertilizer in two different field-grown vegetable crops, processing tomato (*Solanum lycopersicum* L.) and broccoli (*Brassica oleracea* var. *italica*). Therefore, two fertilising trials, one per crop, were conducted for the seasons 2013 and 2014.In addition, this work was undertook to assess the influence of the floraPell application on the soil physico-chemical characteristics after two crop seasons.

2. Materials and Methods

2.1 Processing Tomato Growing Conditions

The fertilising trial in processing tomato consisted of seven different treatments, which are showed in Table 1. One of them is the control treatment, in which none fertilizer is added (TD5). TD1, TD2, TD3 and TD4 treatments applied floraPellat different dosages. Another one applied wool pellets of 8 mm and 8% N (TD6). A commercial organic fertilizer is included as treatment TC (Humibio, (NPK) 6-7-7, Fertinagro Nutrientes, S.L., Spain). These fertilising treatments were established taking into account that the tomato fertilizer needs are 150 N-80 P-160K (Fertilizer Units, kg/ha). To complete the fertilizer necessities of the crop in other nutrients, apart from N, other organic fertilizers were employed (Patentkali® (30% K_2O, 10% MgO; 42% SO_3) K+S KALI GmbH, Germany). In this way, the same quantity of Potassium (K_2O) was applied in each fertilizer treatment, approximately 165 K. The trial plots of the TC treatment were fertilized with 2500 kg/ha of the organic fertilizer 6 N-7 P-7 K (Humibio), so the crop had available 150 N- 175 P-175 K.

The trials were set up at the experimental fields of Centro Tecnológico Nacional Agroalimentario Extremadura (CTAEX), in Badajoz (Spain). The experimental design was randomized, with 4 replications for treatment. The area of each plot was 126 m^2. The same plots were used for each treatment in both seasons.

Processing tomato in Extremadura is grown between April and October. Harvest begins at the end of July and finishes at latest by early October.

Firstly, the land of the experimental field was ploughed and furrowed. The trial plots were marked, and the different fertilizers were applied before planting. The tomato plants were transplanted on the 24th of April 2013 and16th of April 2014, at a planting density of 30000 plants/ha, using a mechanical transplanter (Fialho, Tex Driver). The tomato variety used was H (Heinz)-9661. The weed control was carried out manual and mechanically, and the trial was irrigated through the drop irrigation system (600 mm/year). The crop was grown according with the Organic Farming Regulation (Regulation (CE) 834/2007 of European Commission). The crop was monitored throughout the cycle. In order to control pests (*Helicopervaarmigera*) *Bacillus thuringiensis* was used as pesticide.

The tomatoes were harvested manually from the trial plots when the 80% of them were red and ripened. The harvest took place on 13th of August in the first season and on 4th of August in the second one, from an area of 9 square meters in the center of each elemental plot. The tomato plants were cut off at the base and shaken to make fruits fall into labelled plastic boxes. These tomato samples were used to work out the agronomic and quality parameters.

Table 1 Fertilizer treatments and doses evaluated in processing tomato and broccoli trials.

Processing tomato				Broccoli			
Treatment	**Fertilizer**	**Doses (t/ha)**	**NFU†**	**Treatment**	**Fertilizer**	**Doses (t/ha)**	**NFU†**
TD1	floraPell (10% N)	1	100	BD1	floraPell (10% N)	0.5	50
TD2	floraPell (10% N)	1.5	150	BD2	floraPell (10% N)	1	100
TD3	floraPell (10% N)	2	200	BD3	floraPell (10% N)	1.5	150
TD4	floraPell (10% N)	3	300	BD4	floraPell (10% N)	2	200
TD5	-	-	0	BD5	-	-	0
TD6	Wool pellets 8 mm (8% N)	3.75	300	BD6	Wool pellets 8 mm (8% N)	1.9	150
TC	Humibio (6-7-7)	2.5	150	BC	Humibio (6-7-7)	1.7	100

†NFU: Nitrogen Fertilizer Units (kg/ha)

2.2 Broccoli Growing Conditions

Broccoli trials were performed following the same methodology than processing tomato trials. The fertilising treatments applied to broccoli trials are presented in Table1. For this crop, the trials were designed knowing that the N rate used in this zone is 100 kg/ha N. With the aim of completing the fertilizer necessities of the crop in other nutrients, apart from N, we used Patentkali (30% K_2O).

The trials were established at the experimental fields of CTAEX. The experimental design was randomized with 4 replications for treatment. The area of each plot was 126 m^2. The same plots were used for each treatment in both seasons.

After cultivating the land and the experimental plots were marked off, floraPell and the rest of the organic fertilizers were applied. The planting took place on 5th of September of 2013 and on 22nd of September, respectively for the first and second season. The transplanting density was 35000 plants/ha. The broccoli variety used was Parthenon (Sakata). The weed control was done manual and mechanically, and the irrigation system was drop irrigation (350 mm/year). Broccoli crop was grown according with Regulation (CE) 834/2007 of European Commission regarding organic farming. The crop was monitored throughout the whole crop cycle, taking into account all kind of possible incidences, such as pest events, illnesses, and undesirable weather conditions, among others.

The broccoli is usually harvested in two or three times, because not all the broccoli heads appear at the same time. One head per plant is collected. The broccoli harvest began when the heads reached a diameter of about 0.15 m, which is considered desirable for the commercial requirements in this area. In these trials the broccoli heads were harvested between the 7th and 20th of January of 2014 for the first season, and between the 21th of January and 3th of February of 2015 for the second season. The harvests were performed manually.

2.3 Soil and Climatic Conditions

Before the fertilizers application, a soil sample was taken in the plot for each trial, processing tomato and broccoli, in the first season (2013). The processing tomato plot soil was Fine Sand, showed a slightly acidic pH (6.47), a low conductivity value (144.76 μS/cm), so no salinity problems are expected. The Nitrogen content was low (0.01%), and the Phosphorus (P_2O_5) content was high (58.53 ppm), as usual in this zone. The C/N (Carbon/Nitrogen) ratio was medium (15) while the Total Organic Matter (TOM) was low (1.19%). As for the broccoli plot soil, at the beginning of the trials, the texture was Loamy Fine Sand, with a slightly acid pH (5.73), and no salinity problems (Conductivity = 176.23 μS/cm). The C/N ratio was high (20), the N content was 0.07% and the P_2O_5 content was high (66.85 ppm) too, likewise the TOM (3.35%).

Climate data were obtained from Extremadura Government webpage, and belong to the Meteorological Station network situated all over the region. The weather data for these trials are downloaded from the nearest meteorological station CTAEX experimental field, which is called "El Bercial". Fig. 1 shows the average temperature and the effective monthly precipitation for the season 2013/2014, for processing tomato crop cycle (April-August) and for broccoli crop cycle (September-January). The effective rainfall or precipitation is defined as the quantity of the total precipitation that can be used by the plants. It depends on several factors, such as the rainfall intensity, dryness of the weather, soil inclination or humidity content in soil. In dry climates it is considered that rainfalls bellow 5 mm doesn't add humidity to soil. Fig. 2 shows the average temperature and the effective monthly precipitation for the season 2014/2015. The climate of this area is a Mediterranean climate, with mean annual precipitation around 400-500 mm. One of the most important characteristics of precipitation is its interannual variability, with a dry season, from June to September, and a wet season, from October to May. Summer are hot, with temperatures sometimes rising above 40°C.

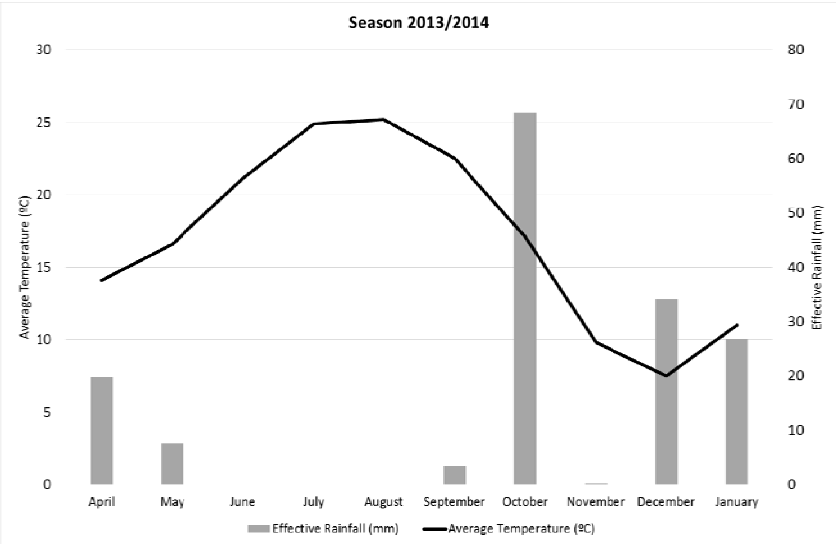


Fig. 1 Climodiagram corresponding to the season 2013/2014.

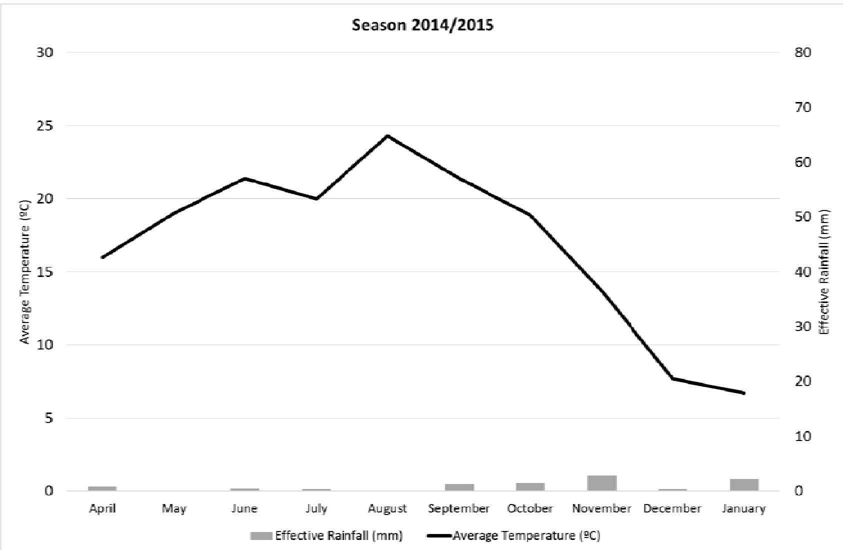


Fig. 2 Climodiagram corresponding to the season 2014/2015.

2.4 Agronomic Parameters

2.4.1 Processing Tomato

The harvested tomatoes of each plot were classified into different groups based on their size, the stage of ripening and the health of the fruits, using a selection line to grade the tomatoes. The agronomic parameters evaluated were Total yield (kg/ha), Commercial yield (kg/ha), Green tomatoes or unripened tomatoes (%), Over ripened tomatoes (%), Sun damaged fruits (fruits affected by the sun, with yellowish spots) (%) and Fruits with blossom-end rot (with dark spots on the bottom of tomatoes, caused by imbalance of water in the plant) (%). The Mean weight of fruit (g) was worked out from 50 fruits from the Commercial yield group.

2.4.2 Broccoli

The agronomic parameters measured in broccoli were the Total and Commercial yield (kg/ha), as the sum of the yields obtained in the two harvests per plot and fertilizing treatment, by weighting every broccoli head harvested per plot. Unmarketable or non-commercial heads included those that were misshapen or with symptoms of bacterial head rot (*Erwinia* spp., *Pseudomonas* spp.). Others parameters were the Mean weight of a head (g) and the Mean diameter of a head (cm), which were evaluated from a sample of 10 representative broccoli heads per plot.

2.5 Quality Parameters

2.5.1 Processing Tomato

The quality parameters were measured on a sample of red and ripened tomatoes (2 kg) from each plot per fertilising treatment. Each sample was processed to obtain a juice according to the methodology described by de la Torre et al. (1999) [21]. This process involved an enzymatic deactivation and removing the seeds and peels, and the air of the obtained juice.The quality parameters measured were: sugar content (ºbrix), colour and viscosity. Sugar content was measured by aBelligham & Stanley mod. Rfm81 at 20°C. To determine the colour of the juice, a Gardner, Colorgard System 2000/05colorimeter was used. Colour was described as coordinates: lightness (L), redness (a) and yellowness (b). The ratio a/b is a good indicator of colour in tomatoes [22]. The viscosity (cm/30s) was determined by aBostwickconsistometer.

In addition, the firmness (g) of the fruit was measured by means of compression tests using a TA.XT2 of Stable Micro — System,texture analyzer, connected to the XTRAD programme; with a cylindrical flat-plate probe, 100 mm in diameter, a displacement velocity of 2 mm/s an a deformation of 2%.

2.5.2 Broccoli

A visual scale, using the values 1, 2 and 3, was employed to evaluate the colour (1 = pale green, 3 = dark green), head tightness (1 = the tightest, 3 = the less tight) and bead size (1 = fine, 3 = thick) of the broccoli heads. These parameters were determined from a sample of 10 representative broccoli heads per plot.

2.6 Soil Analysis

With the aim of investigating the impact of soil amendment by use of the wool pellets, a test plan was designed. Soil samples were taken throughout a two years lasting process, and these soil samples were analysed to evaluate the nutrients on soil and the texture of the soil. Each plot of the fertilising trials designed to evaluate the growth of plants (processing tomato and broccoli) was sampled in these moments: before applying the fertilizers and planting the crops and throughout the crop cycle of growth, one sample per month. The initial soil sample belonged to the whole trial field, and the soil samples taken throughout the crop cycle corresponded to each experimental plot. Soil samples were taken according to the standard method of the Institute of Plant Pedology and Biology of CSIC (Spain). This method includes the following considerations: i) sample should be representative of the plot; ii) samples are taken at a depth of 20 cm; and iii) each sample will consist of 15-20 subsamples, which will be collected in different points, in zigzag, along the plot, and will be kept in a plastic bag to be transported to the laboratories. The parameters measured in soil samples were the pH, conductivity (extract 1/5 µS/cm) by conductimetry, Nitrogen (%), using Kjeldahl methodology. The macronutrients (Phosphorous (Olsen, ppm), Potassium (meq/100g), Calcium (meq/100g), and Magnesium (meq/100 g)) and micronutrients (ppm) (Copper, Iron, Manganese, Zinc and Boron) were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The Oxidizable Organic Carbon (OOC) (%), Oxidizable Organic Matter (OOM) (%) and Total Organic Matter (TOM) (%) were measured by oxidation ($Cr_2O_7K_2$), and finally the soil texture was determined with a Bouyoucosdensimeter.

2.7 Statistical Analysis

The statistical analysis of the data was performed using one-way analysis of variance, and the means were separated by Tukey's honest significant difference test using SPSS for Windows, 15.0.

3. Results and Discussion

3.1 Agronomic and Quality Results for Processing Tomato

Over the vegetative development of the processing tomato crop, some differences between plants from each treatment were observed in both seasons. The TD5 (Control) tomato plants, which were not fertilized, showed the palest green colour and the lowest development, while plants fertilized with higher dose treatment, as TD4 (floraPell, 300 N) and TD6 (wool pellets 8% N, 300 N), showed higher density, number of leaves and a more intense green colour. The TC (Humibio) treatment plants showed a good development throughout the crop cycle. Therefore, the "dosage effect" of wool pellets was observed in these trials.

Table 2 presents the agronomic parameters obtained once processing tomatoes were harvested. The total yield obtained for processing tomato in this trial, as the average of the two seasons, ranged between 55 t/ha and 106 t/ha. TD4 (floraPell, 300 N) and TD6 (wool pellets 8% N, 300 N) treatments produced the highest total yield, significant different from values obtained by TC (Humibio), TD5 (Control) and TD1 (floraPell, 100 N) treatments. The TD2 (floraPell, 150 N) and TD3 (floraPell, 200 N) treatments showed good results of total yields, 87 and 92 t/ha respectively, taking into account that the average total yield for processing tomato in Extremadura under conventional farming used to be around 80 t/ha [18]. The total yields obtained for this crop under organic farming are usually lower than the yields obtained with conventional farming. Gragera et al. (2003) reported values of yield ranging from 53 to 90 t/ha, for conventional farming processing tomatoes [23]. Similar results were obtained by Fortes et al. (2013) and Torres-Vila et al. (2003) [18, 19]. The highest value of commercial yield was produced by TD4 treatment (71 t/ha), which was significantly higher than the commercial yield obtained with TD1 (48 t/ha), TC (46 t/ha) and TD5 (35 t/ha) treatments. Similar results were reported by Gragera et al. (2003) [23]. As for the over-ripened fruits, TD5 (Control) treatment presented the highest value, and was significantly different from the rest of the treatments. This fact could stem from the lack of nutrients, especially Nitrogen, as none fertilizer was applied to TD5 plots. Nitrogen is an important component of many structural, genetic and metabolic compounds such as amino and nucleic acids, proteins and chlorophyll [24]. Processing tomato plants under such stress situation tend to ripen before than fertilized or non-stressed plants. On the other hand, the percentage of green fruits were high in these trials for all the fertilising treatments, ranging between 15.8% (TD4) and 20.4% (TC), although no significant differences were found. These results indicate that the harvest could be performed some days after in order to obtain a higher net yield. However, all the plots of the trials were harvested the same day to evaluate the effect of

Table 2 Agronomic results from tomato trials. The data showed are the means ± sd (standard deviation) of results from the seasons 2013 and 2014.

Treatment	Total yield (kg/ha)	Net yield (kg/ha)	Over-ripened fruits (%)	Green fruits (%)	Sun-damaged fruits (%)	Blossom-endr otfruits (%)	Mean weight of fruit (g)
TD1	74444^{bc}±11766.69	48111^{bcd}±7829.76	3.15^{b}±0.71	18.56±6.43	8.58±3.05	2.75^{ab}±1.89	71.16±3.53
TD2	86972^{ab}±13339.65	53861^{abcd}±12560.08	3.63^{b}±0.56	19.73±9.57	8.71±3.57	4.36^{ab}±1.71	71.68±4.65
TD3	91611^{ab}±4708.81	58472^{abc}±14682.74	2.81^{b}±1.20	19.54±8.21	7.40±2.78	5.12^{a}±2.30	72.67±2.27
TD4	106055^{a}±16163.84	71430^{a}±14662.75	3.41^{b}±0.70	15.87±7.75	7.53±2.00	4.09^{ab}±1.10	71.86±3.44
TD5	54666^{c}±13804.04	35000^{d}±5414.51	6.58^{a}±0.50	16.72±6.46	5.91±2.01	2.53^{ab}±1.21	69.80±0.85
TD6	104527^{a}±5308.10	66111^{ab}±5652.49	3.83^{b}±0.74	19.96±3.09	5.37±0.91	5.46^{a}±0.80	69.40±2.87
TC	72972^{bc}±7718.08	45583^{cd}±5390.48	4.20^{b}±1.11	20.40±5.25	9.02±2.83	2.10^{b}±1.69	67.80±5.09
P	*0.00*	*0.00*	*0.00*	*0.88*	*0.23*	*0.00*	*0.19*

abcd Mean values followed by the same letter within each column do not differ significantly ($p < 0.05$).

the fertilising on the tomato fruits maturation. The level of sun-damaged fruits was around 7.5%, and significant differences were not appreciated among the fertilising treatments. The highest values of blossom-end rot fruits were observed for TD3 and TD6 treatments, with over 5% of these fruits. These values turned out being significant different from TC blossom-end rot values. Tabatabaie et al. (2004) attributed the blossom-end rot appearance to the lack of calcium [25]. The transport of calcium towards the root is linked to the mass flow of water [26]. This is the reason why this physiological effect is related to imbalance of water irrigation. With respect to the mean weight of fruit, non significant differences were found among the treatments. The highest value was observed for TD3 treatment fruits (73 g), whereas TC showed the lowest mean weight of fruit (68 g). Gragera et al. (2003) found similar results for this parameter [23]. These results indicate that the differences found in total and commercial yield among the fertilising treatments are owing to a higher number of fruits rather than a larger size of the fruit.

Regarding the quality parameters of processing tomato, according to the obtained results (Table 3), it seems that the fertilising treatments evaluated do not influence the final product quality, at least in a significant way. The sugar content (°brix) varied between 4.7° (TC) and 4.93°brix (TD6). These results were slightly lower than reported by Fortes et al. (2013) [18]. Gragera et al. (2003) reported sugar content values ranging from 4.6 to 5.4 °brix, which is the level, at which industry will supplement the contracted fresh tomato price [23]. This characteristic is highly conditioned by the genetic [24], although certain agricultural practice could increase slightly the sugar content of processing tomato fruits. Sugar content is one of the most important technological or quality parameter, because it indicates the yield of the industrial process, the higher the sugar content, the higher value of processing yield [25]. Yield and flow attributes of the finished products are of commercial importance. It is generally believed that properties related to consistency and solid contents largely determine finished yield and flow ability [27]. The viscosity is a feature to get to know the ability of the tomatoes to be processed for ketchup or other products, once the tomato paste have been manufactured. In these trials the viscosity values ranged between 19.29 (TD6 and TD5) and 20.25 (TD4) cm/30 s. TC tomatoes showed the highest value of colour (a/b) (1.96), while TD6 and TD2 showed the lowest value (1.91). These colour values were lower than those evaluated by Gragera et al. (2003) and Fortes et al. (2013), around 2.5. Finally, the best firmness was observed for TD4 fruits, and in turn, the worst value was found for TD5 tomatoes. The firmness is an important quality parameter, because harvested tomatoes have to stand many hours in the truck until they are received in the factory, under very hard weather conditions. Tomato firmness is a very important component of internal fruit quality, both in terms of commercialization and of the assessment of organoleptic properties [28, 29].

3.2 Agronomic and Quality Results for Broccoli

The agronomic and quality parameters for broccoli trials over the two seasons are included in Table 4. BD6 (wool pellets 8% N, 150 N) treatment showed the highest value of total yield (10951 kg/ha), and along with BD3 (floraPell, 150 N) and BD4 (floraPell, 200 N) treatments, were significantly higher than BD5 (No fertilizer) total yield (7445 kg/ha). It is worth mentioning the "N effect" observed for floraPell (10% N) treatments, because the more N quantity applied, the higher total yield. In other studies have been demonstrated that the broccoli yield increases with increasing N rate either linearly or curvilinearly [30, 31]. Conversely, BC (Humibio, 100 N) treatment showed the same level of total yield as BD1 (floraPell, 50 N), 7445 kg/ha and 7528 kg/ha respectively, instead of the treatment that applied the same N units, BD2 (floraPell, 100 N) (8096 kg/ha), although no significant differences were found among them. These yield values were lower than those reported by Bakker et al. (2009) [32]. The percentage of unmarketable heads, due to wet damages, ranged between 5.0% (BD2) and 8.26% (BD6), but no significant differences were observed among the fertilising treatments. As for the

Table 3 Technological results from tomato trials. The data showed are the means ± sd (standard deviation) of results from the seasons 2013 and 2014.

Treatment	ºbrix	Viscosity (cm/30s)	Colour (a/b)	Firmness (g)
TD1	4.72^{a}±0.31	20.23^{a}±2.80	1.94^{a}±0.05	4649.17^{a}±626.08
TD2	4.88^{a}±0.36	19.59^{a}±3.09	1.91^{a}±0.05	4916.21^{a}±530.63
TD3	4.80^{a}±0.16	19.36^{a}±2.56	1.94^{a}±0.05	4928.03^{a}±602.56
TD4	4.84^{a}±0.27	20.25^{a}±3.88	1.94^{a}±0.07	5022.05^{a}±682.02
TD5	4.78^{a}±0.42	19.29^{a}±1.45	1.93^{a}±0.08	4294.63^{a}±99.82
TD6	4.93^{a}±0.31	19.29^{a}±0.82	1.91^{a}±0.07	4684.96^{a}±502.63
TC	4.70^{a}±0.21	19.31^{a}±2.22	1.96^{a}±0.05	4929.68^{a}±497.12
P	*0.79*	*0.98*	*0.57*	*0.41*

[abcd] Mean values followed by the same letter within each column do not differ significantly ($P < 0.05$).

Table 4 Agronomic results from broccoli trials. The data showed are the means ± sd (standard deviation) of results from the seasons 2013 and 2014.

Treatment	Total yield (kg/ha)	Non marketableheads (%)	Mean weight of a head (g)	Mean diameter of a head (cm)	Colour (a/b)	Beadsize	Head tightness
BD1	7528^{ab}±2183.99	6.40±4.82	369.93^{a}±123.78	15.96^{a}±1.77	2.28^{b}±0.35	1.4±0.31	1.4±0.56
BD2	8096^{ab}±2546.70	5.00±3.47	349.74^{a}±73.15	15.96^{a}±1.26	2.38^{b}±0.42	1.37±0.32	1.2±0.28
BD3	9139^{a}±3909.42	7.46±6.00	403.30^{a}±86.00	16.76^{a}±1.25	2.45^{ab}±0.24	1.4±0.25	1.12±0.12
BD4	9329^{a}±3433.98	7.19±6.39	442.71^{a}±75.55	17.28^{a}±1.17	2.53^{ab}±0.22	1.48±0.27	1.23±0.26
BD5	3964^{b}±1578.11	4.56±2.76	172.88^{b}±59.16	12.14^{b}±2.00	2.96^{a}±0.05	1.50±0.16	1.50±0.43
BD6	10951^{a}±1404.79	8.26±5.46	391.84^{a}±64.90	16.86^{a}±1.09	2.73^{ab}±0.19	1.29±0.14	1.14±0.02
BC	7445^{ab}±2389.35	7.10±6.51	391.46^{a}±115.55	16.27^{a}±1.80	2.31^{b}±0.38	1.37±0.24	1.25±0.34
P	*0.03*	*0.91*	*0.00*	*0.00*	*0.01*	*0.78*	*0.45*

[ab] Mean values followed by the same letter within each column do not differ significantly ($P < 0.05$).

size of a broccoli head, determined as the mean weight and the mean diameter of a head, both parameters showed the same trend. For floraPell (10% N) treatments, a higher size was observed when increasing the N applied, whereas BD6 and BC treatments showed the same size of a broccoli head. On the contrary, BD5 treatments presented significantly lowest values of mean weight of a head (173 g) and mean diameter of a head (12 cm).Slightly lower values were obtained by Schellenberg et al. (2009) at a 100 N rate, who also concluded that average head weight and diameter were increased with higher N rates [31]. Stamatiadis et al. (1999) reported similar results for head weights after compost and nitrogen fertilizer applications [33]. These authors also found that broccoli head weight and leaf N content were significantly correlated to soil nitrate-N, thus illustrated the relevance of this indicator in soil quality assessment from plant productivity and health perspectives. In the same line, Patriquin et al. (1993) obtained a significant correlation between leaf and soil nitrates in organically fertilized lettuce [34]. In addition, Zheljazkov et al. (2009) evaluated uncomposted wool-waste as a nutrient source and as soil amendment and their results denoted that wool-waste addition increased the N content of basil and Swiss chard plant tissue and N uptake with the harvest [2]. The improved yield parameters associated with higher N rates are supported by the higher percentage of N accumulation in leaf tissue [31].

Regarding the quality parameters, BD5 broccoli heads showed the highest value of green colour, so the darkest green colour, being significant different from the treatments which applied lower N quantities, such as BC, BD1 and BD2. This fact is conflicting because for BD5 treatment heads the palest green was expected, as no fertilizer was applied and it was noticeable for the rest of measured parameters. According to Bakker et al. (2009) under low nitrogen conditions, heads often develop undesirable characteristics such as enlarged flower buds and yellow or purple discolouration [32]. For bead size and head tightness, consumers or processing factories preferred the lowest values, so the lowest values are considered as the best ones for both parameters. The bead size values varied from 1.29 (BD6) to 1.50 (BD5), while head tightness values ranged between 1.12 (BD3) and 1.50 (BD5), although no significant differences were observed for both parameters. A number of quality characteristics and diseases/disorders of broccoli are influenced by fertilizer management practices[32]. Fabek et al. (2012) concluded that fertilization influenced the broccoli quality, in such a way that the highest content of nitrogen, individual and total glucosinolates was achieved by fertilization with the highest rates of nitrogen [35]. The effects of nitrogen rate on visual quality attributes (head shape, density and colour) have reported in a greenhouse broccoli production system. The greatest proportion of plants with desirable quality characteristics (domed, solid emerald to blue-green heads with a low incidence of hollow stem) was achieved at the highest rate of applied nitrogen [36].

3.3 Evolution of soil Characteristics for Processing Tomato Trials

Throughout the whole trial (two seasons), eight soil samples were taken, but in this report just the initial and the final results are included for each treatment. The results presented are the average of the 4 replications.

Soil texture was not modified by fertilizers application and it was Fine Sand for the trial plot. Table 5 depicts the evolution of some of the soil physico-chemical characteristics. The pH increased in a significant way at the end of the trial (8th month, 2nd season), respect to the initial pH for all the treatments. Nevertheless, Zheljazkov et al. (2009) reported that the addition of uncomposted wool-waste to growth medium may decrease soil pH, which might counteract a potential positive effect of the released N on biomass yield [2]. Conductivity value was 145 µS/cm at the 1st month and ranged between 118 and 237 µS/cm at the end. For some treatments (TD1, TD2, TD3, TC) the conductivity increased over the trials, but salinity

Table 5 Soils characteristics in processing tomato trial over the seasons 2013-2014. The first row shows the initial values (month 1st = April 2013), before fertilizer application. The following rows include the values obtained for each treatment at the end of the trial (month 8th = July 2014) and the *p-value* (*P*) resulted from comparing the final value in each treatment with the initial one for each soil parameter.

Treatment	pH (1/2.5)	C.E. (μS/cm)	N (%)	P_2O_5 (ppm)	K_2O (meq/100g)	Ca (meq/100g)	Mg (meq/100g)
Month 1 (Initial)	6.5^{1}±0.00	144.7^{1}±0.00	0.01^{1}±0.00	58.53^{1}±0.00	0.36^{1}±0.00	0.68^{1}±0.00	0.20^{1}±0.00
TD1	7.0^{2}±0.12	236.8^{a2}±35.31	0.05^{2}±0.01	71.65^{ab2}±7.55	1.05^{2}±0.38	3.06^{2}±0.40	1.05^{a2}±0.14
P	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*	*0.00*	*0.00*
TD2	7.1^{2}±0.12	154.9^{bc1}±16.88	0.04^{2}±0.01	82.48^{a2}±4.53	0.87^{2}±0.15	2.72^{2}±0.33	0.80^{b2}±0.06
P	*0.00*	*0.27*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
TD3	6.6^{1}±0.82	177.2^{ab1}±40.03	0.04^{2}±0.01	79.86^{ab2}±6.93	0.76^{2}±0.21	2.63^{2}±0.37	0.78^{b2}±0.06
P	*0.74*	*0.16*	*0.01*	*0.00*	*0.01*	*0.00*	*0.00*
TD4	7.1^{2}±0.17	136.2^{bc1}±17.27	0.05^{2}±0.01	79.36^{ab2}±10.01	0.83^{2}±0.24	2.80^{2}±0.34	0.76^{b2}±0.07
P	*0.00*	*0.36*	*0.00*	*0.01*	*0.01*	*0.00*	*0.00*
TD5	7.3^{2}±0.02	122.1^{c2}±8.68	0.04^{2}±0.01	77.65^{ab2}±5.41	0.69^{2}±0.07	3.24^{2}±0.66	0.81^{b2}±0.11
P	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
TD6	7.2^{2}±0.10	117.5^{c2}±15.75	0.05^{2}±0.01	80.58^{a2}±17.15	0.67^{2}±0.12	3.31^{2}±0.25	0.82^{b2}±0.07
P	*0.00*	*0.01*	*0.00*	*0.04*	*0.00*	*0.00*	*0.00*
TC	7.0^{2}±0.20	204.9^{ab2}±51.52	0.05^{2}±0.01	58.74^{b1}±6.93	0.66^{2}±0.20	3.05^{2}±0.63	0.89^{ab2}±0.05
P	*0.00*	*0.06*	*0.00*	*0.95*	*0.02*	*0.00*	*0.00*

^{1,2} Mean values followed by the same number than the initial value (month 1st) do not differ significantly (P<.05).

^{abc} Mean values followed by the same letter within each column (for month 8th) do not differ significantly (P<0.05).

problems were not expected. TD1 treatment soil showed the highest conductivity data, and was significant higher to the rest of the treatments, except for TD3 and TC. TD5 and TD6 treatments exhibited the lowest soil conductivity values. Nitrogen, Potassium, Calcium and Magnesium content in soil increased significantly for every fertilising treatment at the end of the trial. The Ca increase in soil is a positive effect because it contributes to reduce the incidence of the blossom-end rot, which is the main physiological disorder contributing to decrease the fruit quality of tomato [25]. Phosphorous content in soil also raised significantly for all the treatments except for TC. Significant differences among the treatments were observed for P content and Mg content. TD6 treatment showed the highest P content in soil in July 2014, and was significantly different from TC treatment. As for Mg content in soil, TD1 treatment showed the highest value, different from all the treatments except for TC, in a significant way. For the rest of the soil parameters, no significant differences were observed among fertilising treatments (Table 5).The parameters related to organic matter content in soil, Oxidizable Organic Carbon (OOM), Oxidizable Organic Matter (OOM) and Total Organic Matter (TOM) (Fig. 3), kept at the same level at the end of the trial respect to the initial situation, and most of the treatments showed a slightly increase, but a significant increase was observed for TD5 and TD6 treatments. Organic matter is an important constituent of biologically active and productive soils. The use of organic amendment may result in a soil that has greater capacity to resist the spread of plant pathogenic organisms, thereby requiring reduced use of fungicides [3, 13] and induce biochemical pathways in crops involved in pathogen defence and stress tolerance [14]. The improvement in overall soil quality may reduce the nutrient contamination of ground and surface water and produce more and vigorous-growing and high-yielding crops [36]. Regarding micronutrients content in soil, Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn) and Boron (B) content were analysed(data not shown).Overall, the micronutrients content increased in a significant way for all the treatments, for every nutrient except for Fe and B, which content decreased at the end of the trial respect to the initial values. These results suggest that the soil characteristics evolution does not seem to be conditioned by fertilizers application, because it was similar for all the fertilising treatments, including the control, in which none fertilizer was applied.

3.4 Evolution of Soil Characteristics for Broccoli Trials

Likewise for processing tomato trial, throughout the whole broccoli trial (two seasons), nine soil samples were taken, but here just the initial results and the final results are included for each treatment.

Soil texture, defined by clay, silt and sand percentages, was not influenced by fertilizers application. The experimental field for broccoli trials was quite homogenous and the texture was Loamy Fine Sand. In Table 6 the soil characteristics for broccoli trial are displayed. The pH increased significantly for every treatment, except for BD4 treatment, where it maintained constant. BD4 showed the lowest value, significant lower than BD3 and BD1 treatments. Conductivity also raised in a significant way for all of the treatments, ranging between 229µS/cm (BD2) and 300 µS/cm (BD4) at the end of the trial, while the initial value was 176 µS/cm. N and P content in soil slightly increased over the two seasons, but not significantly. Nitrate-N could be increased during this period as a result of mineralization and nitrification of soil organic matter [30]. For K, Ca and Mg content significant differences between the beginning and the end of the trial were not found, so these nutrient contents maintained at the same level for all the fertilising treatments. A slight increase was observed for K content in soil for every treatment, except for BD5 and BD6, and the final values varied from 1.18 meq/100g (BD6) to 4.28 meq/100g (BD4), which was significantly higher than BD5 and BD6 soil K content. The opposite trend was observed for Ca content in soil,

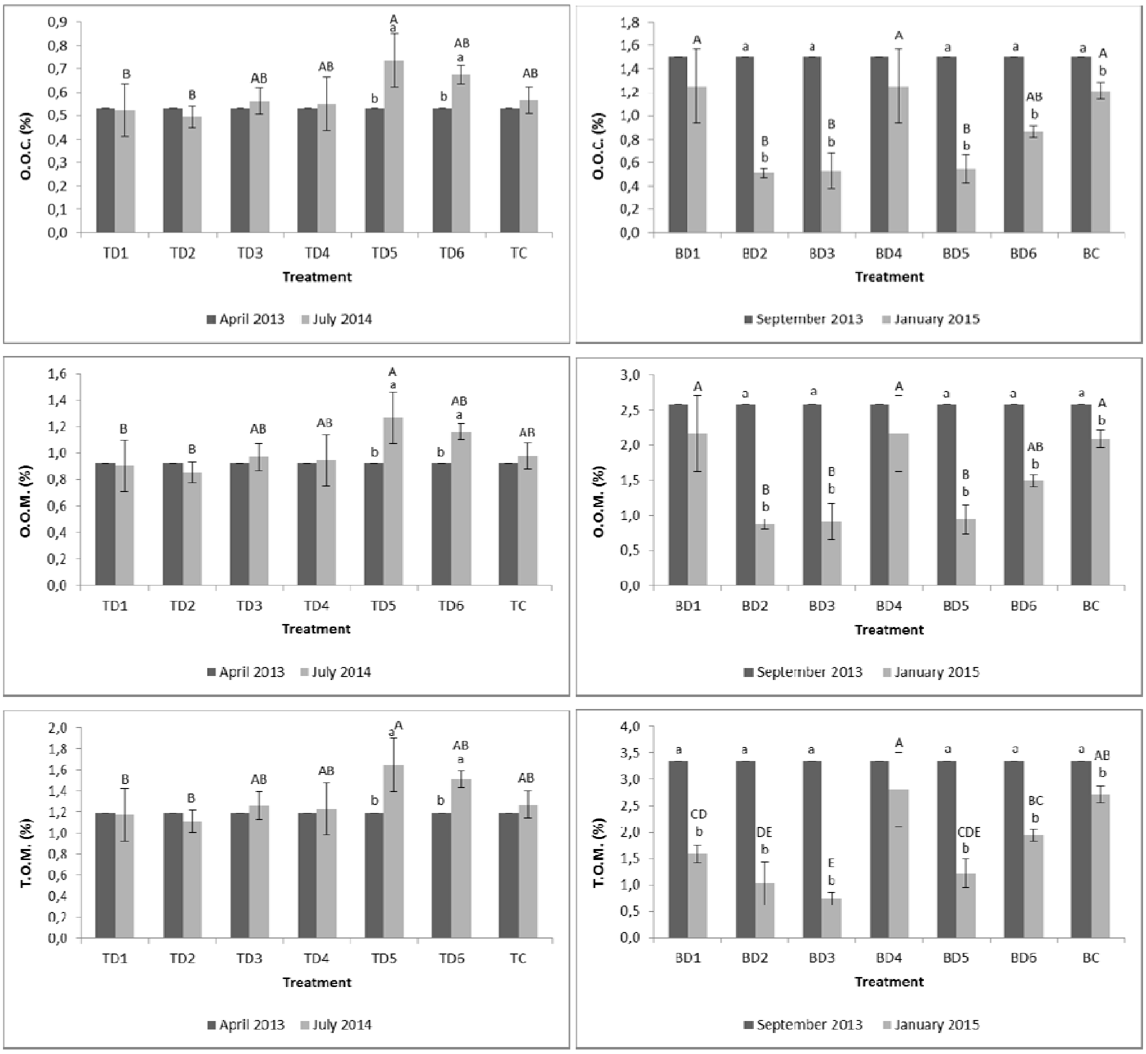
Table 6 Soils characteristics in broccoli trial over the seasons 2013-2014. The first row shows the initial values (month 1st = September 2013), before fertilizer application. The following rows include the values obtained for each treatment at the end of the trial (month 9th = January 2015) and the *p-value* (*P*) resulted from comparing the final value in each treatment with the initial one for each soil parameter.

Treatment	pH (1/2.5)	C.E. (µS/cm)	N (%)	P_2O_5 (ppm)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)
Month 1 (Initial)	5.73^{1}±0.00	176.23^{1}±0.00	0.07^{1}±0.00	66.85^{1}±0.00	1.85^{1}±0.00	3.93^{1}±0.00	1.15^{1}±0.00
BD1	6.51^{a2}±0.40	272.34^{2}±45.11	0.08^{1}±0.02	80.24^{1}±19.42	2.50^{ab1}±0.96	5.04^{1}±2.84	1.31^{1}±0.41
P	*0.01*	*0.01*	*0.32*	*0.2*	*0.23*	*0.46*	*0.45*
BD2	6.13^{ab2}±0.22	229.07^{2}±22.37	0.08^{1}±0.02	77.64^{1}±17.04	1.90^{ab1}±0.62	3.43^{1}±0.74	1.18^{1}±0.38
P	*0.01*	*0.00*	*0.56*	*0.25*	*0.87*	*0.22*	*0.89*
BD3	6.32^{a2}±0.34	248.49^{2}±43.24	0.09^{1}±0.04	78.57^{1}±14.27	2.93^{ab1}±1.95	3.73^{1}±1.10	1.00^{1}±0.24
P	*0.01*	*0.02*	*0.37*	*0.15*	*0.31*	*0.73*	*0.26*
BD4	5.75^{b1}±0.12	300.32^{2}±87.71	0.09^{1}±0.03	80.66^{1}±14.36	4.28^{a1}±2.31	3.64^{1}±0.65	1.13^{1}±0.40
P	*0.79*	*0.03*	*0.32*	*0.10*	*0.08*	*0.41*	*0.93*
BD5	6.17^{ab2}±0.01	273.28^{2}±79.22	0.06^{1}±0.01	80.37^{1}±8.50	1.20^{b1}±0.44	3.47^{1}±0.23	1.15^{1}±0.06
P	*0.00*	*0.03*	*0.32*	*0.10*	*0.08*	*0.41*	*0.93*
BD6	6.12^{ab2}±0.17	240.00^{2}±39.73	0.08^{1}±0.02	75.70^{1}±7.67	1.18^{b1}±0.73	3.80^{1}±0.55	1.18^{1}±0.12
P	*0.00*	*0.02*	*0.57*	*0.06*	*0.11*	*0.66*	*0.62*
BC	5.99^{ab2}±0.12	248.82^{2}±9.91	0.10^{1}±0.05	92.35^{1}±23.51	2.00^{ab1}±0.78	5.27^{1}±1.90	1.27^{1}±0.33
P	*0.00*	*0.00*	*0.26*	*0.07*	*0.72*	*0.21*	*0.49*

[1,2] Mean values followed by the same number than the initial value (month 1st) do not differ significantly ($P < 0.05$).

[abc] Mean values followed by the same letter within each column (for month 9th) do not differ significantly ($P < 0.05$).

as at the end of the trials the values were lower (3.43 (BD2)-3.80 meq/100 g (BD6)) than at the beginning (3.93 meq/100 g), except for BD1 and BC (5.04 and 5.27 meq/100g, respectively). Mg contents were higher at the end of the trial than at the beginning (1.15 meq/100g) for all the treatments, ranging between 1.18 and 1.31 meq/100g, except for BD3, BD4 and BD5 treatments. These nutrients relationships, antagonism between Ca and other nutrients, such as Mg and K, have been described widely [38, 39].With regard to the evolution of Organic Matter (Fig. 3) in soil, a moderate decrease was observed for all of the treatments. OOC values dropped from 1.5% to an interval between 0.46 and 0.90% at the end of the trial, while OOM fell from 2.58% to a range between 0.80 and 1.55% for the last sampling date. Therefore, the TOM decreased from 3.35% to values varying from 0.63 and 2.01% at the end of the trial. Considering the differences among the treatments in January 2015, BD1, BD4 and BC treatments exhibited significantly higher values for OOC and OOM, than BD2, BD3 and BD5 treatments, while BD4 showed the highest value of TOM, different from the rest of the treatments in a significant way, except for BC. The observed trend for organic matter evolution in the broccoli trials was the contrary to



A. Processing tomato B. Broccoli

Fig. 3 Organic Matter parameters evolution in soil over the processing tomato trial seasons (A) and over the broccoli trial seasons (B).

the evolution observed for processing tomato trials. The slower nitrification of N and the high cation exchange capacity of organic amendments stabilize soil chemical properties by increasing soil buffering capacity and slowly releasing essential nutrients for more sustainable plant growth. Increase soil buffering capacity is one of the benefits of building up soil organic matter through compost application [33]. In addition, the micronutrients contents in soil were analysed over the broccoli trials. The Cu content in soil increased moderately for all the treatments, except for BD1. Cu values at the end of the trial ranged between 1.20 and 1.94 ppm, and BD3, BD4, BD5 values were significantly different from the initial value, 1.19 ppm Cu. The Fe content fell at the end of the trial respect to the initial value (43.22 ppm) for every treatment, except for BD3 (57.04 ppm) and BD4 (66.64 ppm), where significant differences were observed. The final Fe content in the rest of the treatments ranged between 11.42 (BD1) and 42.10 (BD2) ppm, with significant differences for BD1, BD5 (31.35 ppm) and BD6 (25.12 ppm) treatments. As for the Mn in soil, its contentraised from 10.72 ppm at the beginning to an interval between 12.32 and 22.95 ppm (BD4), with significant differences for BD4 treatment, although the Mn content decreased in a significant way for BD5 (8.63 ppm) and BD6 (7.48 ppm). Zn content increased slightly from 2.54 ppm at the beginning to a range from 2.83 ppm (BD2) to 3.63 ppm (BC), but also a significant decrease was observed for BD1 (1.49 ppm) and BD6 (2.23 ppm) treatments. Finally, the B content dropped moderately for all the treatments from an initial value of 0.30 ppm, being significant for some of them at the end of the trials, as BD1 (0.20 ppm), BD3 (0.16 ppm), BD5 (0.10 ppm) and BD6 (0.08 ppm). It is worth mentioning that, overall, micronutrients trends were similar in both trials, processing tomato and broccoli, while some micronutrients increased over the two trial seasons, such as Cu, Mn and Zn, the rest of the micronutrients, Fe and B,decreased. Hydrolysed wool was used to enhance the phytoextraction of Cu and Cd from soil and its influence on the bioavailability of metals in soil was studied, and it was proved that hydrolysed wool increased the uptake of Cu and Cd, so it was an important new chelating agent, which could enhance phytoextraction [4]. Water-free wool from domesticated sheep consists mainly (ca. 97%) of wool proteins, the remainder being made up of ca.2% structural lipids, ca. 1% mineral salts, nucleic acids and carbohydrates [40]. Proteins and free amino acids have the ability to complex metals [41]. Besides that, acidification of the rhizosphere increases the mobilization of micronutrients from soil particles, being this strategy one of the main acquisition mechanisms of nutrients by plants and microorganisms in soil [42].To sum up this part of the work, the addition of floraPell as soil organic amendment bring about some little changes in soil properties, like an expected increase in nitrate-N.

4. Conclusions

In summary, the floraPell fertilizer (10% N) worked out better than the rest of fertilizers included in the trials. The application of floraPell at a doses of 2000 t/ha, providing 200 N, ensure a good yield for both processing tomato and broccoli crops, with acceptable quality of the final products. Nevertheless, further research about the influence of floraPell application as soil amendment is necessary to identify the benefits on physical, chemical and biological properties of the soil, as it is expected. Thus, the organic fertilizer *floraPell®* is not only an alternative marketing opportunity for not salable wool represents, but also sustainable and environmentally friendly alternative to mineral fertilizers.

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