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Deliverable A1.D1

Requirements and limitations over the current PLA twine for hop growing sector

Deliverable prepared by associated beneficiary **Lankhorst Euronete Group** in collaboration with coordinating beneficiary **Slovenian Institute of Hop Research and Breweing**

Abstract

This document outlines the state of the art of plant guiding systems, their usage in protected and outdoor crops and typical requirements. Compostable twine guides based on man-made polymers have been in use now for the best part of a decade whilst their adoption and particulars with regards to their development and end of life options are discussed. The Elite BIO twine, made by Lankhorst, is now used worldwide in protected crops. The hop crop places a particularly interesting challenge, due to the fact that the loads experienced by the twine are higher than any crop in which the compostable bio-twines have been used before, but also because the growing season for the crop is very short when compared to the typical 11-month long seasons used in greenhouses for crops such as tomato or peppers. The crop also poses a new dimension for the product namely due to the specifics of the installation of the twine and that the production is outdoors. This calls for a put-up optimization that will allow a lower installation cost for the growers. Finally, a set of product requirements that take into account both the exposed information and potential improvements that will be developed for this twine. The report of the their response of the first growth season testing in hop fields and harvesting machines within the Action A1 of the BioTHOP project is included.

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1. Introduction

Plant training has been carried out since ancient times, with the aid of posts, frames and as of late, with trellis systems. The goal of the support is to optimize the exposure of the plant to sun, facilitate pruning and harvesting, and to maximize the available crop area for maximum yields.

During the 20th century and with the widespread adoption of polymers, there was a significant increase in the usage of first polyethylene (PE) and then polypropylene (PP) fibres, tapes and twines for the supporting of crops. There were significant advantages for the new material. The natural fibre twines that were used had a tendency to rot and sometimes couldn't last a whole season, could be attacked by fungi, eaten by rodents, were hard to handle and in some cases due to issues in the natural fibre crops, there could be not enough natural fibre to support the plants.

The introduction of PP twines removed most of the aforementioned issues, even though the polymer also had its own set of problems. For starters, PP is sensitive to UV-radiation, which leads to an accelerated oxidation process with a gradual reduction in molecular weight and mechanical properties. This means that once the polymer is exposed to natural light, the polymer would degrade, initially at a slow rate but due to the autocatalytic nature of the degradation process, it'd quickly lose its strength and plants would fall. With time, UV stabilisers were developed and these in time became better and more effective.

The first generation of UV-stabilisers were effective and their adoption was widespread. Nevertheless, the usage of chlorine-containing agrochemicals and the introduction of sulphur as a fungi-fighting tool, both lead to the premature degradation of the UV stabilisers and the onset of radiation-induced PP oxidation. Eventually chemically-resistant UV stabilisers were developed. These are the state of the art stabilisation systems used nowadays in PP twines.

The good performance of PP twines as a plant support brought nevertheless a new problem. Whilst natural fibre yarns could be disposed of together with the plant waste and left to decompose naturally, the PP yarn would not degrade so easily and could not be composed together with the green waste. There were three solutions to this problem:

1. Separation. The plants would be separated from the PP twine. The PP twine would then go to landfill and the green waste to a composting process. This is a very expensive process and very labour intensive. It could be done in small parcels but it quickly became obvious that this was not an option as the harvested areas started growing and the size of the farms increased.
2. Landfill. If the waste could not be separated, then it'd all go to landfill. This was also OK in the past but once that landfill quotas started to become scarcer, the price per ton of waste to be managed started to climb and this also became more difficult as an end-of-life option.
3. Burning. Finally, the last option was burning, either in a controlled manner for the production of energy, with checks and balances on emission, or just burning the waste by the producers. This last option is becoming more difficult as the controls on emission are becoming more stringent.

By the end of the 20th century, high molecular weight polylactic acid (PLA) became available in industrial quantities after Natureworks developed the ring-opening polymerization method. PLA had been known for decades but the production cost was so high that this compostable polymer was limited to usage in biomedical applications.

PLA is well suited for support as plants since it is compostable and could be managed as one together with the green waste. Nevertheless, the polymer's difficulty in processing and little documentation available made it extremely difficult to turn into a usable product. Lankhorst Euronete Portugal started working on the development of PLA twines in 2002. The development of this product took 5 years and the first prototypes were placed in greenhouses in the 2007-2008 season. The product was launched in the Horti Fair in Amsterdam in 2010 and was aimed as a support twine for tomato and peppers in protected crops.

The adoption of the new twine was sluggish at the beginning since the twine was more expensive than PP, both due to the higher cost of the raw materials, but also due to the lower strength of the polymer which meant using a higher runnage for the same crop. In the end, pressure from the composting companies which handled the waste at the end of the crops, and the significant savings at the end of the season, lead to a faster adoption rate.

The Elite BIO twine is now used worldwide in protected crops and is undergoing the certification process for the OK-compost Industrial standard.

Hop crops offer a new challenge to the Elite BIO due to the fact that the crop is outdoors, exposed to wind, rain and hail, which imposes significant both static and dynamic loads, not existing in protected crops. The weight of the plant is also significantly higher. Whereas pepper and cherry tomato plants weigh around 1.5 - 2 kg, and heavy tomato varieties up to 6 kg per plant, hop plants can reach up to 11 kg. The season is also much shorter than typical tomato and pepper crops where the Elite BIO twine is normally used and this may lead to potential down-gauging of the product, with a lower cost to the growers. Finally, and as discussed in the project proposal, the twine should strive to be home compostable.

All these aspects will be analysed individually in order to propose the rational development of a PLA-based compostable supporting twine well suited for the hop industry. The development should focus both in the added value that the twine brings to the crop and the reduction of its environmental impact, but also to added-value options for the waste stream generated during the production of hops.

2. Protected versus outdoor crops

In Europe, in 2017, 64.8 million tonnes of vegetables were produced. From those, just over a quarter were tomatoes (Eurostat, 2018). Tomato plants are typically supported in order to maximize their productivity.

Due to the advantages in yield and possibility to shield crops from potential pests, the area of greenhouses installed and production of tomato has grown significantly in the last decades.

The production of tomatoes in greenhouses has reached very high yields, surpassing 100 tons of tomato per hectare (Ruijs, 2011). This high yields are obtained most notably in protected crops in high tech glass-houses with controlled environments. These greenhouses are highly specialized and located in northern Europe where labour costs are high (FAO, 2013). Due to the high labour costs, additional costs in high compostable yarns could be offset by reduction in costs associated with segregation of waste and twine at the end of the season. This lead to the development of the Elite BIO twine, based on PLA which is the only available polymer with a good resistance to UV radiation, acceptable mechanical properties, reasonable cost and readily compostable.

As the market continued to evolve, other countries in southern latitudes started to adopt the Elite BIO twine due to the fact that it simplifies significantly the management of the waste stream for greenhouses.

In the meantime, the product was designed focusing on the needs of typical greenhouse crops, namely peppers, cucumbers, aubergines and tomatoes. These are crops which have a typical load varying between 1.2 kg per plant for the lightest tomato varieties to around 6 kg per plant for the heaviest tomato varieties. The twine is designed also to handle the static load of the plant for the best part of 9 months, with a peak static load during the summer season, lasting around 4 months and little to no dynamic loads.

The twine is also exposed to different chemicals during the crop season, high levels of CO_2, sulphur and to a lesser extent pesticides. This led to the reduction of additives that could interact with these chemicals to a minimum during fibre development. The other variable that needed taking into account in the greenhouses was UV radiation. There are several bio-polymers that have acceptable mechanical properties and compostability and which can be much easier to process than PLA. Nevertheless, most of these are susceptible to UV degradation. Finally, many compostable polymers can also begin to degrade in the conditions typically found in a greenhouse, i.e. room temperature and high humidity. This lead to focusing the product development only in PLA, even though this polymer is not very well suited to the production processes typically used for the production of industrial fibres.

Besides the mechanical and chemical requirements, there are functional requirements that need to be addressed. First, the twine must be able to show a free-fall behaviour, needed during the installation of the twine. This is a very important requirement since it can lead to significant rework in the greenhouse during the installation stage. Other functional requirements include a soft characteristic in order to minimize damage on the stem of the plants and last but not least, the product should be approved for contact with foodstuffs according to the applicable EU and FDA regulations.

The requirements above are for the most part also applicable to outdoor usage. The use of pesticides and chemicals is also applicable to outdoor crops and so is the incidence of UV radiation. The free-fall behaviour is also a key factor in order to minimize costs during installation and so is the soft characteristic and food approval status.

Finally, twines in greenhouses are used in either a knotted or hook configuration. In the knotted configuration the twine is readily tied onto an overhead wire. In the hook configuration, a defined length of twine is wound onto a metal hook (See Figure 1 below). As the plant grows and reaches the overhead wire, a portion of twine is unwound from the hook and the plant lowered and moved across. The result is a plant that grows sideways as it comes out of the substrate and eventually follows the twine up towards the hook (See Figure 2).

Figure 1. Tomato crop on metal hook in greenhouses.

Figure 2. Substrate and sideways growth on tomato plants grown on hooks.

Knot and hook configurations have a very different stress concentration factor, hence different loads can be placed on the same twine used in the two different configurations. In the case of hooks, higher loads can be hang on the twines and this leads to potential down gauging possibilities. The knot type has also a marked effect on the performance of the knotted twine but most users tend to opt for a variation of the slippery hitch which allows a skilled operator to tie one knot with each hand reducing installation costs (see Figure 3).

Figure 3. Pepper crops on high wire knotted twine.

Beyond the aforementioned requirements, outdoor crops have added requirements with regards to the mechanical demands for the twine. This is due to the fact that inside the greenhouse the plants are shielded from the environment, are kept within a very narrow temperature interval and they're not exposed to rain, hail or wind. Each of these factors will be analysed separately.

1. **Temperature**. There are two factors to take into account when considering temperature and PLA. The first one is hydrolysis. Hydrolysis will become an issue for PLA at temperatures nearing 55ºC in the presence of humidity. Normally, in greenhouses these temperatures are not found since very high temperatures, the same as very low ones, are detrimental to the yield and survivability of crops. When working outdoors, these kind of temperatures cannot easily be found in environments which are appropriate for the production of vegetables. The second factor to take into account is that most properties in polymers show a non-linear response to temperature. In the range where plants can grow, this effect is not significant since the polymer will still be well below the glass transition temperature and well above the ductile to brittle transition temperature (M. R. Kaiser, March 2013).
2. **Rain**. Plants have a hydrophilic high specific surface area which readily adsorbs water. This can lead to a static load increase during rainfall. Considering a typical surface area of leaves for the hop plant of 2 m^2, and a water film thickness of 100 micrometres (Hove E.H., 1996), the maximum weight that the plant will have due to rain is in the order of 1 kg, though it can be as high as 4kg for the heavier Celeia hop variety. This is a significant load that will affect the creep behaviour on the yarns if plenty of rain is observed for extended periods of time, especially at the end of the season.
3. **Hail**. Hail has a similar effect as rain, even though the load from rain is a static load that increases steadily and reaches a plateau, hail will cause short lived dynamic loads on the twine. Assuming an average hail ball diameter of 33 mm, a terminal velocity of 14.5 m/s (NOAA, 2019) and a shock absorption distance of 2 to 5 cm, the load on the twine will be in the order of 3.50 to 8.50 kg per impact. This of course can be increased significantly since many such impacts can occur at the same time. This dynamic loads are better handled by fibres with a high elongation at break, whereas low elongation fibres will not resist shock loads. Typical high elongation fibres can be considered those with an elongation at break over 15 %, though this can vary from application to application.
4. **Wind**. Finally, wind can also lead to dynamic loads which can be calculated using certain assumptions from literature (J. A. Gillies, 2002). For wind speeds of up to 30km/h, assuming a plant distance of 0.5m, 1 stem per plant, 4m high trellis and a Cd of 0.4, the load on the twine is around 3 kilogram force for a tomato plant which is in the order of the weight of the plant. For hop plants, with the higher plant height and considering the same Cd, the load can be as high as 14 kgf for 50 km/h gusts. This is in line with experience from the growers where twine with a strength lower than 35 kgf can lead to premature failure.

3. Plant loads

In greenhouses the main focus on the design of twines are static loads, due to the lack of dynamic loads except for the sacking and harvesting operations and, in the case of hooks, the lowering of the plants. Both static and dynamic loads in greenhouse crops are well known and have led to the development of a type chart wherein Lankhorst sales team can advise and growers can choose the most suitable twine for their crops.

All the crops on which the Elite BIO twine is used nowadays also consists of a single stem, wherein there is a small variation in weight between neighbouring plants. Most variation is observed on the edges of the greenhouses where in most cases the plants show a lower size, and in some rare cases where plants on the edges of the greenhouse show a higher size. In the specific case of hops, different varieties show variation in size and speed of growth and different growers will have a tendency to group more or less stems per twine.

The combination of range in both static and dynamic loads on the twine due to outdoor exposure and the new crop make it difficult to predict the most suitable twine type that should be used for the hop crops.

As a starting point, we can compare the strength of different twines in use. Nowadays several alternatives can be found in the market and are in use in different areas.

In the USA, the most common solution is the use of coir on an 80 m/kg runnage. Coir on the aforementioned runnage has an average breaking strength of 45 kgf, which is rather high for the hop crops. In discussion with growers, it was found that due to the large variation in diameter along the length of the coir twine caused by the inherent unevenness of the fibre, a very high strength was needed in order to sustain the loads of the hop plants. These twines on the other hand have a very high elongation at break due to the high twist construction so dynamic loads due to wind and hail can be easily accommodated. Some growers also use paper twine but dipping in a copper solution is needed in order to prevent the paper twine from rotting at the base of the plant. The application of copper has its own environmental end health issues which has limited the adoption of this twine.

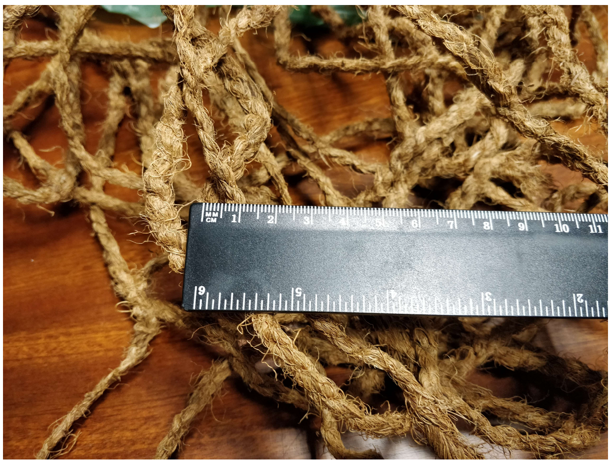


Figure 4. Coir twine used as hop plant support

In Slovenia, different qualities of twine were sampled, all of them in polypropylene. Table 1 below shows a summary of the tested twines and fibres.

Table 1. Mechanical tests on twine used in hop fields in Slovenia. Samples recovered from two different seasons.

Year	Sample	Runnage [denier]	Tenacity [gf/den]	Elongation [%]	Twist level	Breaking strength average [kgf]
2018	Monofilament	11900	4.1	10.9	None	48.8
2018	1200 m/kg (7500 denier)	8560	3.5	14.8	38Z	30.0
2018	1000 m/kg (9000 denier)	9400	4.9	7	33Z	45.8
2015	1000 m/kg (9000 denier)	9000	5.0	11.6	50S	45.0
2015	Monofilament	12764	4.0	11.4	None	51.0

There seems to be three different qualities of twine in use, 700 m/kg (monofilament), 1000 m/kg and 1200 m/kg. These nevertheless fall in two categories, one with a higher strength of 45 to 50 kgf and another one with 30 kgf. These are in line with the requirements placed on the coir used for hops in the US, though the lower strength twine might be better suited for the lighter hop varieties.

For the 1000 m/kg sample recovered in 2018, a very low elongation at break was measured. This can lead to premature failure in dynamic loads. Furthermore, low elongation fibres also tend to show a lower knot efficiency caused by a large stress concentration in the knot area. This stress concentration cannot be accommodated by plastic deformation on the twine due to the low elongation at break of this material.

A further step requires us to compare the typical twine strength with the loads placed on them. In Table 2 there is a summary of the varieties of hops typically grown in Slovenia and the associated load on the twine.

Table 2. Hop variety and plant weight (B. Čeh, 2019)

Variety	Plant load [kg]
Styrian Golding	6.5
Aurora	7.6
Bobek	8.4 (estimated)
Celeia	9.3 – 11

Considering the weight of the plant and using the safety factor developed for protected crops, the strength of twine is grossly over specified. This could be due to the fact that the safety factor used in greenhouses is based on a static load that spans many months at the maximum plant weight. In the case of hops, due to the short time in which the static load is applied before the plant reaches the high wire, the creep deformation is not significant and could have allowed lower runnage twine to be used.

Since Elite BIO has a reasonably high elongation at break that can better absorb energy from dynamic loads, potentially lower runnage could be used in the guiding of hop plants, though this needs to be tested on site and in different hop varieties, growers and regions. The hop varieties affect the static load as a function of the plant weight. The region can affect the dynamic loads due to stronger winds or probabilities of hail. Finally and as mentioned above, different growers can chose to group more or less stems per twine, have a longer or shorter separation between plants and also soil management techniques can lead to yield differences and hence weight differences for the plants.

During the 2019 season, four different Elite BIO types were tested in hop fields in Slovenia in the Lower Savinja Valley region, a demo region of the BioTHOP project. A summary of type and mechanical properties is included in Table 3.

Table 3: A summary of type and mechanical properties of the four different Elite BIO types tested in 2019 in hop fields of Lower Savinja Valley

Elite BIO type	Average dynamic breaking strength
700 m/kg	25 kgf
600 m/kg	30 kgf
500 m/kg	36 kgf
400 m/kg	44 kgf

From the tested samples, the most likely qualities to be used in the future are the 500 m/kg and 400 m/kg due to the strength being closer to the requirements normally placed in PP twines. Both these qualities also showed a survivability that was > 99.5%. Even though 100% is aimed for, there are circumstances in which the twine breaks due to reasons that cannot be easily elucidated.

4. End of life

There are a handful of options for the disposal of green waste at the end of the season. Ideally, a twine to be used in this application will be suitable to be used in all of them. Below is a summary of the most relevant end of life options and the compatibility of the currently developed Elite BIO twine for each.

Industrial composting

Elite BIO has been designed with the EN13432 standard in mind in order to make the twine compostable in industrial composting environments. The main requirements for the EN13432 is that all the components in the product must be biodegradable in industrial composting conditions, whereas up to 5 wt% can be included of materials which may not be compostable. This percentage is nevertheless limited to 1 wt% per individual component. Henceforth, additives, reinforcing agents or fillers which are not compostable, can only have a maximum loading of 1 wt% per component.

With regards to the composting processes, the main types are briefly described below.

Windrow composting

In this system the green waste is arranged onto windrows, with or without a core. The core is normally an inflatable tube which is later on used to pump air into the pile in order to control the evolution of the composting process. After a certain period of time, the pile is turned, sieved and a second maturation stage is started. After this second stage, the pile is finally sieved and ready for use. This process takes anywhere between 6 to 12 weeks, depending on different variables. This is a reasonably simple process, with relatively low initial investment. Nevertheless, composting facilities need to be designed to handle any liquid leachate from the composting process and to treat it according to the established environmental guidelines. On the other hand, air contamination is an issue with these processes as dust, foul smells and spores become airborne and can cause issues in the areas surrounding the composting facilities.

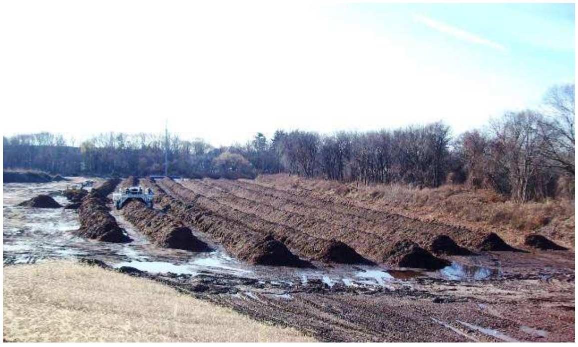


Figure 5. Windrow composting. (Greenville County Soil and Water Conservation District, 2019)

Figure 6. Static compost pile with pepper plant green waste after 6 months

Static pile

This is also normally an open air process, differing from the windrow composting in that the piles are not arranged in windrow configuration but instead in concrete compartments as shown in

Figure 6 below. In the static pile composting process, all the above considerations with regards to emissions need to be taken into account. The static pile process tends to take longer to be completed due to the more difficult access to air inside the pile. Lack of air within the pile can lead to anaerobic composting conditions with emissions of dangerous gases such as methane, which forces the pile to be turned with a certain frequency to minimize the possibilities of fire hazards but also to homogenise the batch since the material on the outside is normally not exposed to the high temperatures found on the inside and this leads to differences in compost quality.

Static pile processes can be carried out both in a central composting center but also on site. In Figure 6, a static pile composting operation is shown wherein a pepper grower in Belgium does his own composting and then reuses the compost in his own fields.

Aerated tunnel

This is the preferred system with regards to emission control. The first part of the process is done in an aerated tunnel with forced ventilation. The process is controlled via a closed loop system which manages the temperature of the process by the injection of air and humidity by a water spray located on the roof of the tunnel. This process is normally composed of two stages, with one or more cycles in each stage. The first stage takes place in the tunnel, where the initial composting takes place. Initially the process goes through a thermophilic phase, with temperatures as high as 70ºC for two days. After this phase is completed, the temperature is reduced to 55ºC and the process continues for up to 15 days. After this first operation, the compost is sieved and it could go through a second tunnel cycle or into maturation. Maturation takes place in piles outside the tunnel and either indoors or outdoors. Finally, the compost is again sieved and ready for use. In this process, all emissions are carefully controlled and the air is filtered and processed in order to avoid any foul smells or spores to be sent into the atmosphere. These kind of processes can take place in populated areas due to the good level of emissions control.

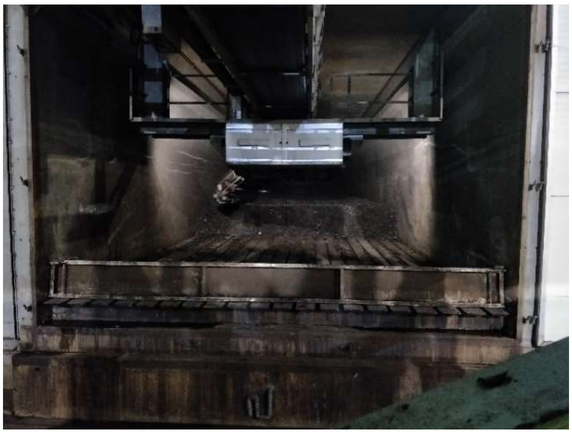


Figure 7. Compost tunnel with automatic filling system in operation

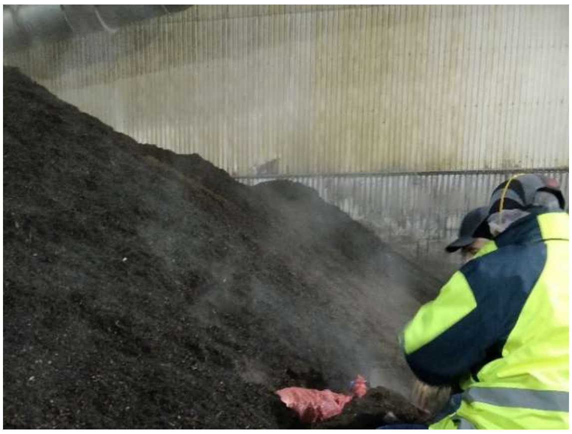


Figure 8. Indoor compost maturation stage

Anaerobic degradation

Anaerobic degradation is a waste valorisation process wherein the degradation takes place in the presence of limited amounts of oxygen. In these conditions, biogas and a fertilizer are produced. The biogas can be reused for the production of heat or energy, and the resulting CO_2 produced can also be used to accelerate growth of species such as tomato plants in high tech greenhouses.

If the right conditions are not met during a composting process and the composting pile does not get enough oxygen, the conditions for anaerobic digestion could be met, leading to the production of methane and risk of explosion. Also, the quality of the compost is not met since the outside of the pile might not get the same exposure to the high temperatures found inside the pile, leading to an inhomogeneous quality compost and only partially degraded twine and plants.

Home composting

There is another composting process which is carried out typically in garden bins or small enclosures. Typically in home composting bins the maximum temperature tends to be lower than that found in industrial composting operations and can be as high as 45 ºC, which is well below the glass transition temperature of PLA (European Bioplastics, 2015). In these conditions, the degradation of PLA can take significant amounts of time. Since home composting bins can also suffer from lack of proper maintenance and the quality and frequency of addition of green waste can vary significantly, the quality of the compost cannot be guaranteed. Nevertheless, a comparative study of compost produced in home composting bins versus industrial composting plants has shown that comparable quality compost can be obtained from both processes (R Barrena, 2014).

There are also home composting certifications such as those offered by TÜV Austria, formerly Vinçotte, which aim at setting guidelines for products that can be composted in these more demanding conditions, although no standards or regulation are currently available (European Bioplastics, 2016).

There are some limitations with regards to the home composting process. Since the waste stream generated by hop crops is well beyond any home composting process, this is a good to have functionality more than a potential value-adding characteristic.

The real added value for the hop crops would be nevertheless, the reduction in degradation time in order to complete the process efficiently onsite using a static pile process. This is better suited for the typical size of farms in the hop industry and uses tools already available to the growers. An investment in an enclosure to guarantee the handling of any leachate coming off the compost pile could eventually be needed in order to comply with local emission regulations.

Due to lack of installed composting capacity in some markets, reducing the speed of degradation in home composting conditions can bring significant added value to some growers. This can be achieved in a series of ways, such as using different polymers as additives or catalysts (A Araújo, 2013). Even though there is a possibility that this pathway could be used in fibres, clays tend to have a particle size which might not be compatible with the fibre production processes. Other clays such as Kaolinites could be approached instead, which can be obtained with very small particle size and tight distribution.

Biodegradation performance of Elite BIO twine

Green waste containing Elite BIO twine has been reported to successfully degrade under windrow, static pile and aerated tunnel composting processes. Most of the composting is done in northern Europe in both static pile and aerated tunnel by composting companies. Some growers do effectively carry out composting on site which allows them to produce and reuse their compost, notably in Belgium and also in France in the norther region of Brittany.

We have not had any reports from the market regarding the use of Elite BIO twine in anaerobic digestion processes. Nevertheless, PLA has been reported in the literature as digestible in these conditions (S Hobbs, 2019). The ideal conditions for PLA are when the temperature in the reactor is above the glass transition temperature for the polymer, i.e. 55 ºC. The potential for methane production of PLA twine was measured to be in the order of 55 % of PLA transformed onto methane (H Yagi, 2009).

5. Exposure to chemicals and weather

The requirements with regards to weather exposure have been described above. Considering UV degradation, the Elite BIO twine has been used in a high UV radiation area (Canary Islands) for two consecutive seasons. After the two seasons, the twine was tested and the strength reduction was negligible confirming the fact that the raw material is not affected by this radiation.

There are other polyesters which can and will degrade upon exposure to visible light or that can undergo discoloration due to sun radiation. Nevertheless, this is not an issue with the polymers used in the Elite BIO twine and all pigments and additives are chosen to withstand sun and weather exposure as long as these requirements do not conflict with the compostability and food-contact criteria defined above.

Both in greenhouses and in open air crops, agrochemicals tend to be used in order to control pests but also as fertilizers or additives to accelerate fruit ripening. A subset of those allowed to be used in hop crops in Slovenia is summarised in the Table 4.

Some of these chemicals are known to cause issues with polyolefins in greenhouses such as Sulphur or compounds containing halogens. The twine will have to be subjected to some of the most aggressive compounds in order to discard the impact in the mechanical properties. The bacteria can be discarded as this has not been isolated as a bacteria with potential for the digestion of PLA (Kawai, 2010) and also because bacteria can typically only act on PLA after hydrolysis. The conditions for hydrolysis of the PLA twine can only be found after the thermophilic phase in the composting operation hence bacterial or enzymatic attack can be discarded (Huang, 2005).

Table 4. Summary of chemicals used in the plant protection program in Slovenia in 2019 (IHPS, 2019)

Active ingredient	Family	Chemical formula
Fosetyl-Al	Fungicide	$C_6H_{18}AlO_9P_3$
Fluopicolide	Fungicide	$C_{14}H_8Cl_3F_3N_2O$
Copper hydroxide	Fungicide	$Cu(OH)_2$
Copper oxychloride	Fungicide	$Cu_2(OH)_3Cl$
Folpet	Fungicide	$C_9H_4Cl_3NO_2S$
Azoxystrobin	Fungicide	$C_{22}H_{17}N_3O_5$
Mandipropamid	Fungicide	$C_{23}H_{22}ClNO_4$
Sulfur	Fungicide	S
Myclobutanil	Fungicide	$C_{15}H_{17}ClN_4$
Potassium hydrogen carbonate	Fungicide	$KHCO_3$
Metrafenone	Fungicide	$C_{19}H_{21}BrO_5$
Trifloxystrobin	Fungicide	$C_{20}H_{19}F_3N_2O_4$
Pymetrozine	Insecticide	$C_{10}H_{11}N_5O$
Flonicamid	Insecticide	$C_9H_6F_3N_3O$
Lambda-cyhalothrin	Insecticide	$C_{23}H_{19}ClF_3NO_3$
Spirotetramat	Insecticide	$C_{21}H_{27}NO_5$
Bacillus thuringhiensis var. kurstaki	Insecticide	Bacteria
Bacillus thuringhiensis var. aizawai	Insecticide	Bacteria
Hexythiazox	Insecticide	$C_{17}H_{21}ClN_2O_2S$
Abamectin	Insecticide	$C_{47}H_{70}O_{14}$
Milbemectin	Insecticide	$C_{31}H_{44}O_7 + C_{32}H_{46}O_7$
Acequinocyl	Insecticide	$C_{24}H_{32}O_4$
Spirotetramat	Insecticide	$C_{21}H_{27}NO_5$
Pelargonic acid	Herbicide	$C_9H_{18}O_2$
Sheep fat	Repellent	

6. Installation and removal

Installation

Due to the high runnage twine needed for hop crops, larger bobbins are better suited in order to minimize the change-over time needed during installation. During installation, assuming a plant density of 2,500 plants per hectare and a runnage of 500 m/kg, the installer would have to change over 9 bobbins if the weight of the bobbins is maintained at the current 4.5 kg put-up. This disrupts the process and increases installation costs unless knots are allowed. For this application nevertheless, joining twine using knots is discouraged due to the low efficiency achieved and the possibility for premature twine failure at this stress concentration points.

Using the current extrusion equipment, 7.5 kg bobbins could be produced. This would reduce the change-over to 5 bobbins per hectare and also reduce the amount of packaging waste.

There are other options like supplying the twine already in cut lengths. For this operation, a cutter could be developed in order to accelerate the installation and minimize the time required in the field to measure and cut the twine lengths.

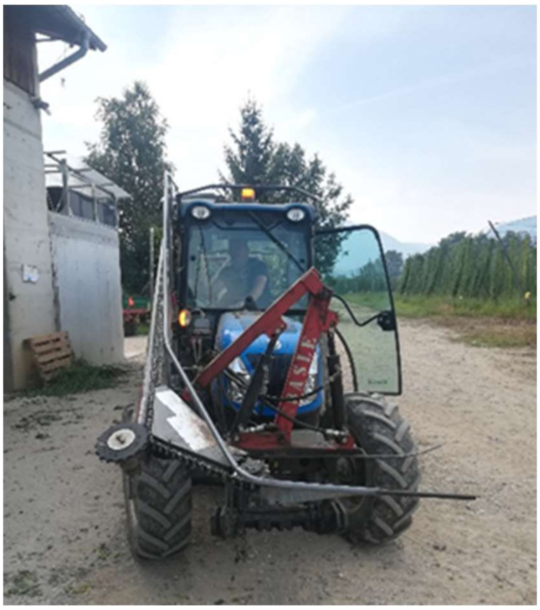
Most of the hop growers hire seasonal workers to do the field work, including the training of the twines in the spring. The twine is attached on the upper side to the wire of the construction by knot, made by the workers on the tractor tower, driving constantly along the hop rows. The lower part of the twine is also knotted and the knot is pushed into the soil by a steel probe. The action of knotting has to be fast therefore the consistency of the twine matters to the farmers as it costs less if the workers are efficient at their work. The twine shouldn't be neither too hard nor too soft and should not be rough, so it sleeps easily from the plastic bag. Too hard twine would be complicated to tie but on the other hand soft one would split on the wire and would be to supple in the hands of a worker. The twine has to meet the needs of both.

Removal

The hop harvest process consists of several operations, namely the cutting the plants on the field approximately 0.5 m above the soil by the device on the front part of the tractor, their removal from the trellis straight afterwards (plants are pulled down by the tractor, the twine must scrape at the top, right next to the wire, the plants fall to the tractor trailer and being transported to the harvest machine), feeding the plants onto the separation machine, separation of the cones from the rest of the plant parts (leaves and stems, intertwined by the twine) in the harvest machine and finally chopping of the hop biomass after harvest.

Each operation has its own requirements as follows:

Cutting of the twines is mostly done by machine. In the past most of the hop plants were pulled from the trellis by hand which is not the case nowadays when the pulling is being replaced by the cutting with the device on the front part of the tractor (Figure 9) and scraping them down by the tractor device. The device cuts the plant and the twine about 0.5 m above the ground or higher, the plants get into a chain system (Figure 10) that pulls down the plant and load it on the trailer. The twine should be strong enough to resist plant weight during the growth season but also week enough to tear though when being pulled by the machine. When the twine is too soft it can clog the chain system and additional time is needed to clean the particular parts of the machine (Figures 11 and 12).



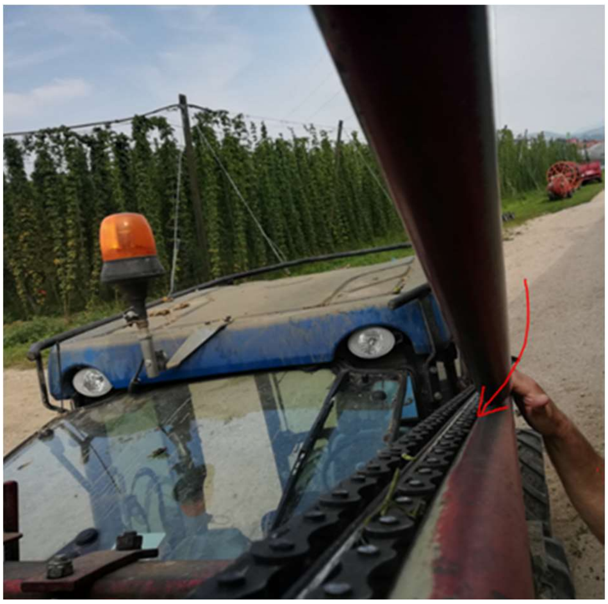
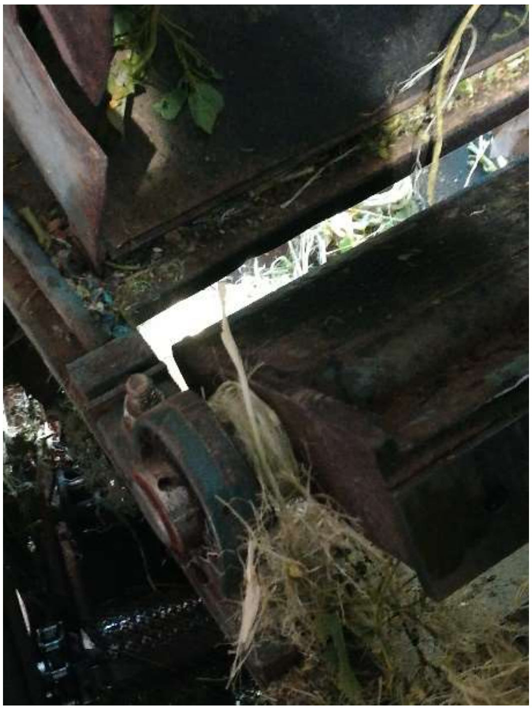


Figure 9: Cutting machine on the front part of the tractor.

Figure 10: The chain system for plant pulling from the trellis.

Feeding onto separation machine and separation of the cones. The feeding is mostly done manually (Figure 13) and does not require special twine properties. It is important to keep in mind is that when the plants are shorter due to hail or drought, the remaining twine should be cut off manually before feeding onto separation machine in order to prevent the overloading of the chopping machine with the twine material.



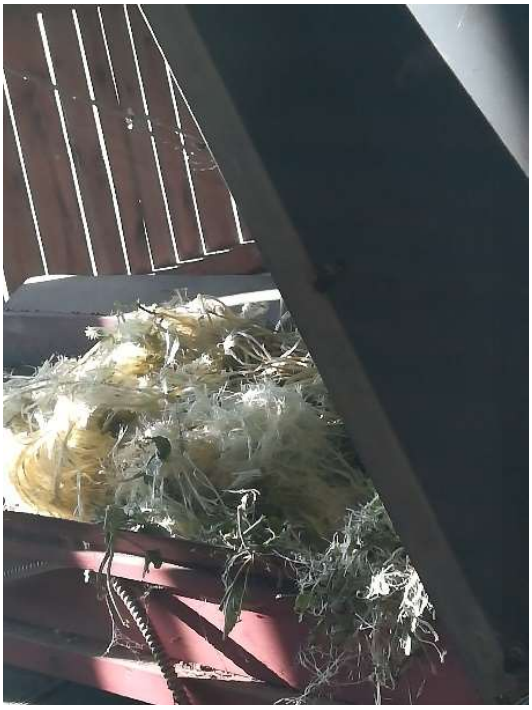


Figure 11: The twine curled around the axle

Figure 12: The amount of twine, removed from the chopper.

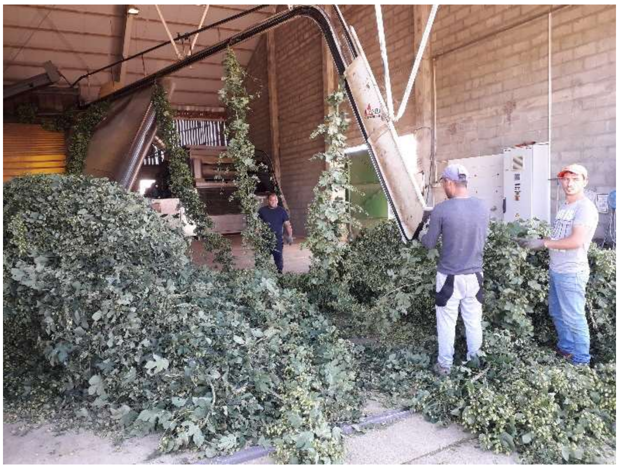


Figure 13: Feeding the hop plants into harvest machine

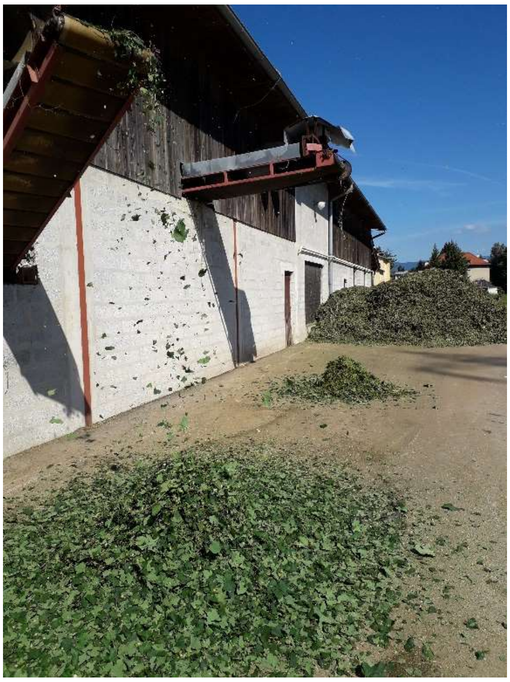


Figure 14: Hop biomass after harvest falling out of the harvest machine separately leaves (left) and chopped twines, intertwined with twine (middle); on the right there is older hop biomass after harvest waiting to be transferred

Chopping the stem. Farmers are using different types of chopping knives. Most of them are using Wolf's chopping knife where the rotating knife cuts the stems on 15 cm long residues. Chopping can be critical point regarding twine as it usually curls around the axle. In case of low plant yield and therefore high ratio between plant stems and twine, the twine clogs the chopper and the process has to be stopped. Softer twine is difficult to chop as it slips through the knife whereas harder twine is chopped easily. Few farmers use other choppers that are more efficient and chop into smaller fragments. It that case the twine consistency is not so important.

7. Product requirements

With regards to the specification of a twine to be used for hop crops, the requirements are defined below:

- Dynamic loads

In order to reliably sustain the dynamic loads, the minimum dynamic breaking strength for the twine must be 35 kgf for the heavier hop varieties with plant weight of 7.5 kg or higher and 30 kgf for the lighter Sterling variety, with a maximum weight of up to 7.0 kg.

- Static load

With regards to the static load, the twine should be able to sustain a maximum load in the knotted configuration in the order of 11 kg for the heavier varieties, with a maximum exposure time of 2 months. For the light varieties, the time is the same but the maximum load is in the order of 6.5 kg.

- Elongation at break

Ideally a high elongation at break of 12% or higher should be aimed for. This will allow a good energy absorption in dynamic loads and lead to a better knot efficiency.

- Put-up

Minimum put-up weight 4.5 kg per bobbin, though this can lead to constant disruption during installation.

If possible, increase the put-up to 7.5 kg per bobbin.

Evaluate the possibility to supply cut lengths of twine.

- Compliance

The twine should be produced with raw materials compliant with the EU regulations No 10/2011 for plastics to come into contact with food

The twine should be produced according to the EN13432 guidelines regarding compostability

- Chemical

The twine should not suffer significant reduction in its mechanical or functional properties when in contact with the chemicals listed above.

- End-of-life

With regards to composting, the twine should aim for efficient onsite composting.

If possible, home composting should be achieved. Nevertheless, as mentioned before, home composting adds very limited value to the growers and on-site composting is the best value proposition for this product.

- Installation and removal

In order to minimize the impact in labour, the product should aim to meet the needs of tying where the twine should be compact to prevent splitting into many parts when making a knot.

Having a stiffer twine would simplify the chopping at the picking machine and prevent additional workload and stoppages.

8. Summary and conclusion

The main characteristics of protected and open air crops have been identified and discussed in detail. With regards to the specifics of open air crops, there are a series of challenges which are new to the product and that can be tackled with small modifications to the product, such as an increase in the minimum elongation at break.

Besides the fact that the twine needs to be used in outdoor crops, hop plants pose a much higher static load on the twine than we have ever encountered on crop supports. This static load by itself means extending the range of twine to beyond the runnage currently in use for Elite BIO twine in order to place a reasonable safety coefficient on the support of these plants. Based on the safety coefficient used nowadays for tomato and pepper crops, the twine would be greatly over specified considering comparable PP products used as hop guides. Extensive testing will be needed in order to develop a twine that can guarantee a well-supported crop and at a minimum cost for the farmers.

One of the end of life options considered in the project proposal was home composting. Considering the available literature and industry standards, it's unlikely that home composting as defined by a garden bin compost system, will be suitable for the hop industry. Typically, home composting systems reach very low temperatures due to the small size of the bins used, hence this poses a challenge on the speed of degradation for PLA. Nevertheless, due to the volume of green waste available, even from the smaller farms, the composting conditions better approach a static-pile on-site composting process. The yarn will be tested in order to guarantee that a good degradation rate and good quality compost can be obtained using these conditions. Documentation should be produced in order to aid the growers in getting a good quality compost that can be re-used in their fields as soil amendment.

The hop industry uses a large variety of chemicals specific to this industry. The twine will have to be tested in order to verify that there is no incompatibility with these and if necessary, adjust the recipe or runnage to avoid any impact on the safety of the crops.

The installation and harvest stages for hops are expensive, labour intensive operations. In order to maintain the profitability of the hops crops, the twine must guarantee minimum impact on these operations. Two important attention points were identified at this stage. The first one focused on the impact of the twine configuration and its effect on the knotting operation. For heavy runnage twines, two or more tapes tend to be twisted together onto a single yarn. Normally this is not an issue but during the installation process in the hop crops in Slovenia it was identified that the twines produced from two tapes had a tendency to increase the time needed to produce a good knot on the high wire. The second issue was the stiffness of the twine. The twine produced from two tapes, even though it had a higher runnage, was a suppler product when compared to the single tape twine. This led to a tendency of the supple twine to wrap around the cutting rolls and causing intermittent stops on the cutting machinery. This effect was reduced or completely absent when using the yarns composed of a single tape, even with a lower runnage. This vital information will help minimize the impact on the cost of the installation and removal operation and will be tested in the upcoming season in Task B2.

Finally, the product requirements have been analysed and will be subjected to potential adjustment once the test results from the first trials in Task A1.1 have been thoroughly analysed.

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