SUSTAINABLE HOP CROP SUPPORT USING COMPOSTABLE PLA TWINES

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Abstract
This report 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 fibres 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 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. The report of results of the first growth season testing in hop fields and harvesting machines within LIFE BioTHOP project is also included. The tests point toward a clear pathway for the rational design and optimization of BioTHOP PLA based twines for an economically and environmentally sustainable hop crop.
Key words: hop, compostable, plant support, polylactic acid

TRAJNOSTNA OPORA HMELJU Z UPORABO PLA VODIL

Izvleček
To poročilo povzema pregled sistemov vodil za rastline, njihovo uporabo in tipične zahteve v zaprtih prostorih in na prostem. Kompostabilne vrvice iz naravnih vlaken so v uporabi že več kot desetletje, zato smo opisali njihove zahteve glede razvoja in možnosti ob koncu sezone. Hmelj predstavlja precejšen izziv za razvoj vrvic, saj je masa obremenitve vodil skoraj dvakrat tolikšna kot pri drugih rastlinah, pri katerih se bio-vrvice že uporabljajo, poleg tega pa je rastna sezona hmelja zelo kratka v primerjavi z drugimi rastlinami, ki imajo 11-mesečno rasno sezono, npr. paradižnik

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ali paprika v rastlinjaku. Specifična je tudi namestitev vrvic in proizvodnja na prostem. Poročilo vključuje rezultate prve sezone testiranja BioTHOP PLA vrvic na hmelju v okviru projekta LIFE BioTHOP. S poskusom smo pridobili podatke, ki bodo omogočili racionalno oblikovanje in optimizacijo vrvic iz PLA za ekonomsko, okolju prijazno in trajnostno pridelavo hmelja.
Ključne besede: hmelj, kompostiranje, opora rastlinam, polimlečna kislina

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 synthetic 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 materials. 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 available for supporting plants.

The introduction of PP twines removed most of the aforementioned issues, even though the fibre also had its own set of problems. PP is sensitive to UV-radiation, meaning that once the polymer is exposed to sun light, the fibre would degrade and 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 (Sedlar, 1982).

The good performance of PP twines as a plant support brought nevertheless a new problem. Whilst twines from natural fibres could be disposed 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 should 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 labour intensive and very expensive process. 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 be sent to landfill. This was acceptable 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 (Farrington D. W., 2005).

PLA is well suited for support plants since it is compostable and could be managed as one together with the green waste. 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 and launched commercially by Lankhorst Euronete as Elite® BIO twine in the Horti Fair in Amsterdam in 2010. The Elite® BIO twine has been used mainly as plant support in greenhouses and in its first 8 years an estimated 38.4 million plants have been supported using this compostable twine. This translates roughly onto 100 000 tons of green waste that was directly sent for composting without further treatment.

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 than pepper and cherry tomato plants that weigh around 1.5 - 2 kg, heavy tomato varieties up to 6 kg per plant, but hop plants can reach up to 11 kg (B. Čeh, 2019).

All these aspects are analysed in this article individually in order to propose the rational development of a PLA-based compostable supporting twine well suited for the hop industry. The development is focused 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 GREENHOUSE PROTECTED CROPS VERSUS OUTDOOR CROPS

In the European Union, 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.

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 plant and twine at the end of the season. This lead to the development of a twine based on PLA (Elite® BIO) which is the only available polymer with a good resistance to UV rays, has acceptable mechanical properties, reasonable cost and is readily compostable.

Besides the mechanical and chemical requirements, there are functional requirements for twines that need to be addressed. First, the twine must be able to show a free-fall behaviour, needed during the installation of the twine. 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.

Beyond the aforementioned requirements, outdoor crops have higher requirements with regards to the properties of a twine. The influences of these factors are as follows:

1) **Temperature**. There are two factors to take into account when considering temperature and PLA twine. The first one is hydrolysis. Hydrolysis will become an issue for PLA at temperatures nearing 55 ºC 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. 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 µm (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 4 kg 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**. 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 if the hail

speed is reduced by half upon impact (ToolBox, 2019). This of course can be increased significantly since many such impacts can occur at the same time.

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 30 km/h, assuming a plant distance of 0.5 m, one stem per plant, 4 m high trellis and a drag coefficient (Cd) of 0.4, the tensile load on the twine is around 30 N 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 dynamic tensile load can be as high as 140 N for gusts of 50 km/h, to which a static 110 N load should be added to account for the weight of the plant.

3 PLANT LOADS

In greenhouses the main focus on the development of a twine is static load. This due to the lack of dynamic load except for the sacking and harvesting operations and, in the case of tomato hooks, the lowering of the plants.

As a starting point, a comparison of strength of different twines in use can be made, where several alternatives can be found in the market and are in use in different areas nowadays.

In the USA, the most common solution is the use of coir of linear density 80 m/kg. Coir on the aforementioned runnage has an average breaking load of 450 N. 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. Coir twine on the other hand has a very high elongation at break, in the range from 25% to 40%, due to the high twist construction so dynamic load 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.

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. 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 450 to 500 N and another one with 300 N. 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 caused by a large stress concentration in the knot area. This stress concentration cannot be accommodated by plastic deformation on twines with low elongation at break (Pieranski P., 2001).

Table 1*: Mechanical properties of polypropylene twines used in hop fields in Slovenia. Samples recovered from two different seasons.*

Year	Sample	Linear density [tex]	Tenacity [N/tex]	Elongation [%]	Twist level	Average breaking load
2018	Monofilament	1320	36.9	10.9	None	478.8 N
2018	1200 m/kg	951	31.5	14.8	38Z	294.3 N
2018	1000 m/kg	1040	44.1	7	33Z	449.3 N
2015	1000 m/kg	1000	45.0	11.6	50S	441.4 N
2015	Monofilament	1420	36.0	11.4	None	500.3 N

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 1*: Hop variety and plant weight (B. Čeh, 2019)*

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

Since Elite® BIO has a reasonably high elongation at break that can better absorb energy at 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.

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 load [N]**
700 m/kg	250
600 m/kg	300
500 m/kg	360
400 m/kg	440

From the tested samples, the most likely qualities to be used in the future are the types 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% during the tests carried out in the field in 2019. 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 engineered in accordance to the EN 13432 standard in order to make a twine that is compostable in industrial composting environments. The main requirements for the EN 13432 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. 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. This process takes anywhere between 6 to 12 weeks, depending on different variables. This is a reasonably simple process, with relatively low initial investment. On the other hand, air and soil 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.

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 below. Static pile processes can be carried out both in a central composting center but also on site. In Figure, 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. 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 2: *Windrow composting. (Greenville County Soil and Water Conservation District, 2019)*

Figure 3: *Static compost pile with pepper plant green waste after 6 months*

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 although no standards or regulation are currently available (European Bioplastics, 2016).

Figure 4: *Compost tunnel with automatic filling system in operation*

Figure 5: *Indoor compost maturation stage*

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.

There have been no reports from the market regarding the use of Elite BIO twine in anaerobic digestion processes industrially. 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 UV DEGRADATION

Considering UV degradation, the Elite BIO twine has been used in a high UV radiation area (Canary Islands) for two consecutive seasons, i.e. two years. After the two seasons, the twine was returned to the lab and tensile tested. The reduction in strength was negligible confirming the fact that the raw material is not affected by UV radiation. Two years is well beyond the time needed for the support of hop plants but clearly shows the extent of the stability of the polymer.

6 INSTALLATION AND REMOVAL

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.

Furthermore, joining bobbins of twine using knots is discouraged due to the low knot efficiency achieved and the possibility for premature twine failure at this stress concentration points.

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 a tractor-pulled platform, driving at a constant speed 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 its packaging. Too hard twine can be hard to tie. Too soft a twine can split on the wire and would be too supple in the hands of a worker. The twine has to meet the needs of both.

The hop harvest process consists of several operations, namely 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, feeding the plants onto the separation machine, separation of the cones from the rest of the plant parts in the harvest machine and finally chopping of the hop biomass after harvest.

7 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 modifications to the product.

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.

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. The first one focused on the impact of the twine configuration and its effect on the knotting operation. The second issue was the stiffness of the twine. This vital information will help minimize the impact on the cost of the installation and removal operation.

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