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AGRIPAP – Executive summary

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Summary

Plastic films are used increasingly in vegetable, berry and fruit production for the prevention of weed growth, control of temperature and moisture of the soil as well as for the prevention of raindrop- and wind-induced erosion. Globally over 80 000 km^2 of arable land is covered every year by plastic mulch films. By using plastic mulch films farmers are capable of improving both the amount and the quality of yields and of decreasing the use of pesticides, fertilizers and irrigation water. Plastic mulch films are made predominantly from polyethylene, that is not biodegradable. Therefore the mulch films should be removed from the soil after each cultivation period. The removal work is laborious and often leaves some plastic mulch film fragments in the soil. Unfortunately, there is no viable use for used polyethylene mulch films, which are typically contaminated by soil and plant residues, but the removed mulch films have to be disposed in landfills. Biodegradable mulch films, which after use can be tilled into soil where they biodegrade, exist on the market. Their use is still relatively limited (the market share is estimated to be less than 10 %) due to the price which is 2-3 times higher than that of polyethylene mulch films. Biodegradable mulch films are used particularly in countries where labour and landfilling costs are high (like in Finland).

The aim of AGRIPAP-project was to develop low cost, well performing paper mulches for replacing the plastic mulch films. Another aim was to establish research methods, test environments and know-how of which paper mills can exploit in their own R&D. AGRIPAP was a three-year co-operation project of VTT (Biomaterial applications) and University of Helsinki (Department of Agricultural Sciences - Agrotechnology). The main task of VTT in AGRIPAP was to develop concepts for manufacture of paper mulches (project 1. AGRIPAP-lab). The role of UH was to test experimental paper mulches in field conditions and to develop methods for use of paper mulches in farming (project 2. AGRIPAP-field). Functioning of the experimental paper mulches were tested in experimental farms in Finland, Spain, Swaziland and Turkey. The industrial partners of AGRIPAP were Walki, Stora-Enso, UPM, Kemira and Avagro. The companies not only financed the project but they also supplied the papermaking pulps, various specially treated experimental paper mulches, the chemicals and the equipment for use of VTT and UH. They also started in-company R&D for paper mulch development.

In the beginning of AGRIPAP there was no clear picture on the paper mulch performance and the development needs, but they were clarified in the field trials carried out by UH in Finland and abroad. In farming, paper mulch should perform comparably to plastic mulches especially in regard to ease of mechanized laying, weather resistance, and ability of the mulch to block light to prevent weed germination. The edges of paper mulches which are buried into soil should resist biodegradation so that the mulch remains anchored to the soil until the weight of the vegetation on the papers will hold them in place. Once the season is complete and the paper mulch is tilled into soil, it should biodegrade so that no harmful accumulation of paper mulch takes place in the soil. Complete biodegradation of the mulch in the soil ensures that

the soil quality remains good and no littering of rural environment takes place.

Field trials showed, that sack paper type of paper mulches made from softwood chemical pulps are so strong and stress resistant that they can be laid on soil using conventional plastic mulch film laying machines after some adjustments. Such paper mulches resist also stresses caused by wind and rain and working in the cultivations. Unfortunately, the edges of the paper mulches, which in normal use are buried in the soil, degrade much too fast. Severity of the problem depends on cultivation conditions and cultivated plants: For example in Spain, where topsoil is typically relatively dry during cultivation season, too fast biodegradation of paper mulches is not a severe problem. However, in Finland and in many other regions the topsoil is both moist and warm during the cultivation season. In such conditions edges of paper mulch made from softwood chemical pulps biodegrade within a couple of weeks i.e. much too fast. Some fast growing plants like melon are capable to cover the paper mulch by branches and leaves and in that way keep the paper anchored on soil despite of biodegradation of the paper mulch edges. In practise, it is also possible with earthing machines to lay more soil on the edges of the papers if degradation occurs before the vegetation has grown heavy enough. However, in the case of paper mulches made from chemical pulp fibres the most important development need is the improvement of decay resistance of the paper.

Paper mulches which are made from mechanical or chemimechanical pulps typically resist biodegradation long enough, i.e. till the end of the cultivation season. By thermo treatment the resistance can be further improved. Unfortunately, those papers do not withstand stress caused by mechanized laying, wind and the impact of people working in the cultivations. The most important development need related to paper mulches made from mechanical or chemimechanical pulp is improvement of their mechanical stress resistance. However, mechanical and chemimechanical pulps could be used as such for the manufacture of long lasting paper board sheets. Such board sheets may find use in perennial cultivations and in forestation where the mulch sheets should remain unbroken at least 2 years. As the mulch sheets are laid manually on the root of plants, the mechanical strength of the board is not so critical property. Experiments carried in AGRIPAP showed, that the main problem of the paper board mulch sheets is their tendency to curl up on the soil.

In the project, various attempts to improve decay resistance of paper mulches were made including addition of different conventional paper making chemicals such as hydrofobizing agents and wet strength agents. A starting point was that all the additives must be safe for environment. Tested specialty chemicals included sulphate lignin, acidic minerals and formates. The biodegradation tests were carried out both in laboratory by simulating field conditions and in real conditions in experimental farms. None of the tested additives improved decay resistance of the papers significantly. Fortunately, in their own development projects the participating companies found some feasible solutions for the problem.

In the project, several attempts were also done for improving the stress resistance of paper mulches made from mechanical or chemimechanical pulps. According to the study, the resistance can be improved by clupak and creping treatments which make the papers more extensible. However, clupak or creping treatments do not solve the problem alone but additional measures are needed. Mechanical mulch laying experiments in UH showed, that breaking of paper mulches can be somewhat reduced by proper adjustment and geometry of the laying machine. Also lowering of the height of soil bed, on which the paper mulch is laid, makes laying of the paper mulches easier. Most promising way to improve stress resistance, especially tear strength, of the paper mulches made from mechanical or chemimechancial pulp is the addition of long (~6 mm) biodegradable fibres such as viscose or PLA fibres in the paper making pulp. Verification of the performance of such reinforced paper mulches in farming is an interesting topic of possible further studies.

The field experiments showed that the best paper mulches perform comparably to conventional polyethylene plastic mulch films and biodegradable plastic mulch films in regard to the prevention of weed growth and control of temperature and moisture of the topsoil. The biggest advantage of biodegradable plastic mulch films and paper mulches is that, due to their biodegradability, they can be tilled into soil after each cultivation season. There is no risk of soil spoilage or littering of rural environment. No laborious removal work and costly landfilling of used mulch is needed. According to calculations carried out in AGRIPAP, there is no significant difference in carbon foot prints of the three different type of mulches as the whole life cycle of the mulches is taken into account. It is evident that regarding overall environmental impacts the chief asset of both biodegradable mulch films and paper mulches is their biodegradability and thus the absence of plastic film waste accumulation in the arable land and environment. Paper mulch makers just have to take care that the biodegradation rate of the paper mulch is decent in the end-use conditions and that all constituents of paper mulches are safe for environment and consumers. In practice the manufactures can apply certificate like Vincotte OK biodegradable SOIL to prove biodegradability and safety of their products in mulch use.

Launch of paper mulches is a big challenge and effort for papermakers. The end product requirements are very different than those of other paper products. On the other hand, during AGRIPAP it became evident that low cost biodegradable mulch is something farmers would like to use in farming. They hope that such products appear in the markets. It is also possible that in some countries like Spain use of non-biodegradable mulch films will be restricted or totally prohibited by authorities. In the future global demand of biodegradable mulches may extend to several million tons per year. The attractive market prospects and promising results of AGRIPAP evoked intensive development work among participating companies. According to field trials carried out in Zaragoza (CITA Aragon, Spain) in summer 2013 the best developed paper mulches are ready for commercialization. Launches of new better performing paper mulches are possible in the near future.

Confidentiality	Public

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VTT, University of Helsinki, steering group members of Agripap–project.

Preface

This report summarizes backgrounds, results and conclusions of Tekes financed Agripap research project (1.5.2010 – 31.12.2013). The aim of Agripap was to develop low cost, well performing paper mulches for agriculture. The project was carried out in cooperation with University of Helsinki (Department of Agrotechnology). The project was partly financed by Stora Enso, UPM, Walki, Kemira and Avagro.

The project was steered by the following steering group: Antti Korpela (VTT), Jukka Ahokas (UH), Raino Kauppinen (*also Petri Väätäjä*) (Stora Enso), Rune Skåtar (Walki), Reetta Strengell (Kemira), Anssi Väättänen (Avagro).

The project partners are greatly acknowledged for very good cooperation and variety of efforts for the project. Tekes is acknowledged for substantial finance of the study and for guidance of the steering group.

Espoo, 28.01.2014

Authors

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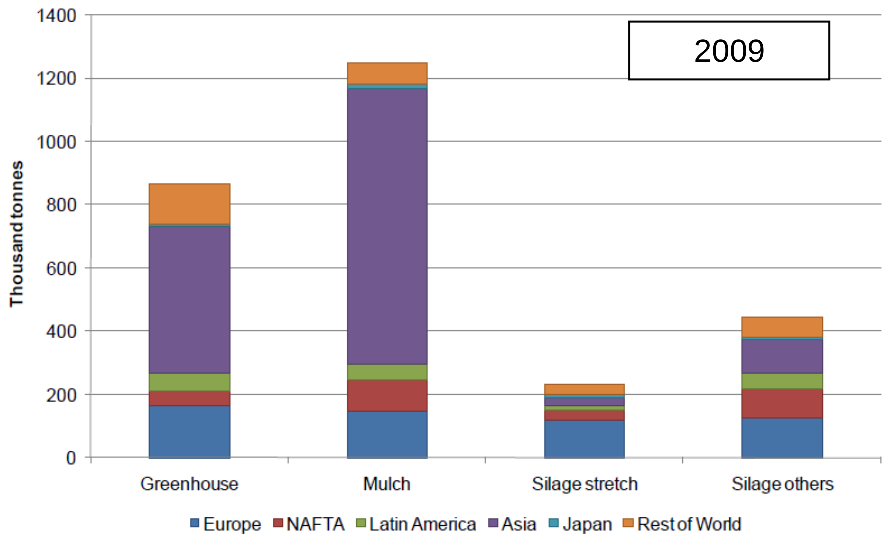
1. Market prospects of paper mulches

Plastic mulch films are used in vegetable, berry and fruit production to prevent weed growth, control of temperature and moisture of the soil and for prevention of rain drops- and wind-induced erosion. When used over a large area, plastic mulches are laid on the soil mechanically. Hand-laying is used mostly in small scale by home gardeners but also in large scale use in developing countries /1/.

Figure 1. Plastic mulching /2/. http://www.alvaplast.com/index.php/mulch-and-micro-tunnel-films.html

Typically, the use of plastic mulches results in higher yields, improvement of yields quality and decreased need of irrigation and pesticides and reduced leach of fertilizers to water systems. Paper such as old newspaper and old packaging board has been used for long by home gardeners. Use of reel paper for mulching started in early 30´s. The use remained limited and practically died down as the low cost plastic mulches became available for the farmers in late 50´s. Also use of plastic mulches remained quite low for decades until rapid growth of use started in 80´s /1,3/. According to A. Reynolds, every year over 80 000 km^2 of agricultural lands are covered with plastic mulch films /4/. Covering of such area by paper mulches, the realistic basis weight being 60 – 100 g/m^2, would mean 4,8 – 8,0 million tonne annual paper mulch demand. This can be compared with the total paper and board production in Finland being around 11 million tonnes in 2011.

During 2000-2007 annual world demand of plastic mulch films increased from 0,54 million tons to 1.4 million tons /4/. Figure 2 shows global demand of plastic mulches in 2009 and a respective forecast for 2015. Most of the mulch films are used in Asia followed by Europe (in 2009 70 % and 13 % respectively) /5/. The present plastic mulch films dominating mulch film markets are made from polyethylene (PE) and they are not biodegradable. Therefore, used PE-mulch films should be removed after the growing season. Due to the adherence of soil to PE-mulch film removal of the film is often very laborious and costly. The used PE-mulch films engaged with soil cannot be recycled economically or used for energy production but in most cases they can only be transported to landfills. This causes significant extra costs to the farmers and thereby restricts the growth of plastic mulch film use in agri- and horticulture. An irresponsible farming practice, which is unfortunately quite common in some locations especially on large area plastic mulch film use, is to plough the used PE-mulch film into soil reducing the next plant yield and quality of the soil (See Figures 4 and 5). The plastic pieces are worked mainly by the cultivation tools and UV-light and they are cut to pieces very slowly causing accumulation of the films in the soil /8/. Another unsuitable practice is to burn the collected plastic film at the farms or dump the used mulch in the surroundings of the farms /9/.



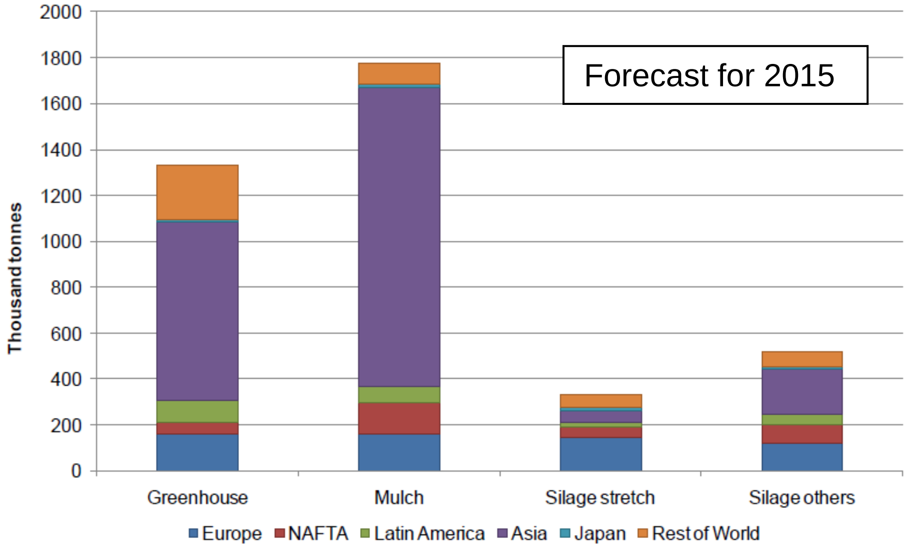


Figure 2. Mulch film demand by type in 2009 and forecasted demand in 2015 /5/.

Availability of low cost biodegradable mulches which could be ploughed into the soil after the growing period would free the farmers from the problems related to use of PE mulch films. To be a viable alternative in farming, biodegradable mulch film should perform comparably, or at least satisfactorily, to polyethylene mulch film in crop production, especially in regard to the ease of mechanized laying, weather resistance, decay resistance and ability of the mulch to block light to prevent weed germination. Once the cropping season is complete, the biodegradable mulch should degrade so that no accumulation of harmful mulch film pieces into the soil takes place.

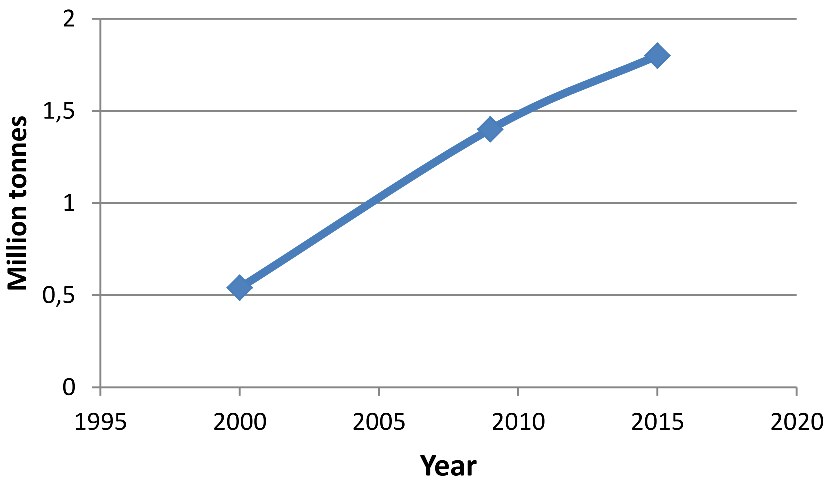


Figure 3. Global mulch film demand /4,5/.

Unfortunately, the present biodegradable plastic mulch films such as Mater-Bi ® and Ecovio ® based mulch films, are 2 – 3 times more expensive (price per kg) than PE-mulch films, making use of the biodegradable option too costly for the farmers /7,10/. Because of the high cost and general poorer performance (lower strength and poorer weather resistance) their present market share is just around 7 % of the total mulch film market /11/. However, the market share is increasing and many experts of mulch film markets expect that in the future biodegradable options will replace PE-mulch films /17/. The driving force is the increasing removal and landfilling cost of used PE-mulch films and concerns related to the pollution of farm land and the environment. Even despite of careful removal work fragments of PE-films tend to remain in soil causing its cumulative contamination by PE-film waste. In Spain, total prohibition of non-biodegradable mulch films is already under public discussion /12/. Some PE-mulch film producers are trying to defend market position of PE-mulch films by promoting the development of recycling systems for the used PE-films and by developing methods for reuse of the film. /13,14/. So far, no breakthrough has come up.

According to a market opportunity study, in 2007, retail price of the commercial plastic mulch films, which with a typical thickness of 16-18 microns (around 16-18 g/m2), was 3.3 - 3.7 $/kg in US /15/. Typical mulch film used in the US is around 120 kg/hectare the purchase price being around 420 $, Sarnace and Wildes state that in the US "a significant cost premium of 50 % or more is feasible if mulch film removal and disposal can be eliminated "/15/. According to a cost estimation done by MTT, the landfilling costs of used plastic mulch were 350 – 420 € per hectare in practice in year 2004. Working costs were not included in the figures /16/. The very high landfilling cost is partly caused by adherence of the soil to the mulch film multiplying weight of the plastic waste. From the figures it can be concluded that the cost premium of 100 % or more (depending on the working cost) is feasible in Finland if mulch film removal and disposal can be eliminated.

Figure 6 visualizes the price competitiveness of the biodegradable mulch films in the US and in Finland. Still relatively small global market share of the biodegradable plastic mulch films (~7 % /11/) is not only due to their higher purchase price: due to the smaller elongation of the biodegradable mulch films their mechanized laying on the soil is not as easy as laying of PE-mulch films. UV-light induced degradation on the soil and too fast biodegradation under the soil can be problems too. Moreover, biodegradable mulch films should be stored in dry conditions. However, the trend is that prices of the biodegradable mulch films come closer to prices of PE-mulch films /6/. Properties of the biodegradable films are improving too. In the future, potential competitors of paper mulches are not just PE-mulch films but also biodegradable plastic mulch films.

Presently, there are several commercial paper mulches on the market,with trade names such as MIMgreen®, ECOkrepp, Planters paper® and EcoCover™ .The products are marketed as biobased, biodegradable and environmentally friendly option for PE-mulch film. Unfortunately, no reliable statistics regarding the market share of paper mulches is available but apparently the share is very small. The reason to this may be too high purchase price and/or unsatisfactory properties of the paper mulches. In the present study, the commercial paper mulches were tested and used as reference mulches for the experimental paper mulches developed in the project.

Figure 4. Agricultural land contaminated by used polyethylene mulch film. (J. Ahokas, Turkey, 2012)

Figure 5. Used plastic mulch film cumulated in the soil /7/

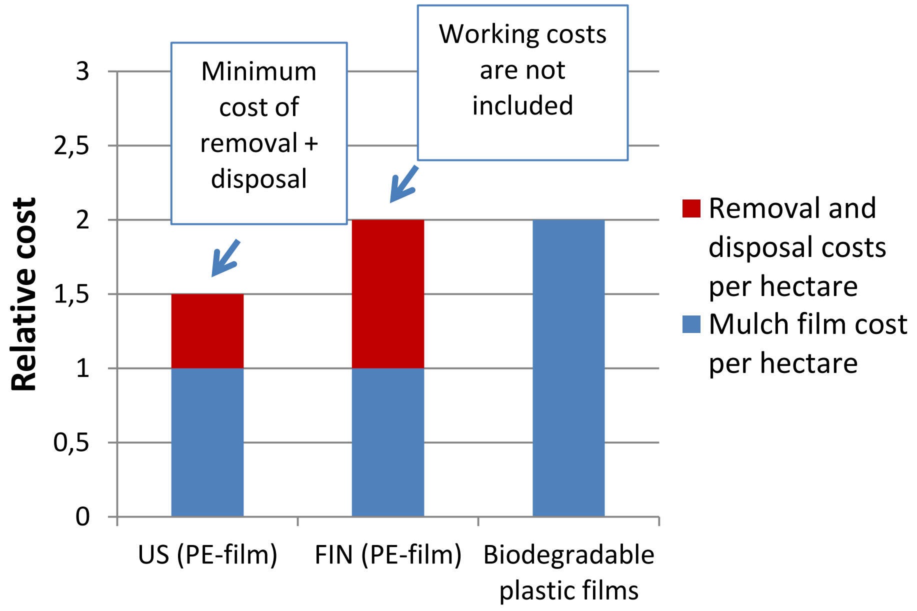


Figure 6. Relative costs of mulch film use in agriculture /15,16/. Cost competitiveness of biodegradable plastic mulch films – and paper mulches -- depend significantly on local circumstances, especially on working and landfilling costs in different market areas.

2. Goals

The main goals of AGRIPAP were:

- Development of manufacturing concepts for well-functioning, price competitive and environmentally friendly paper mulches for global mulch markets.

- Establish the research methods, test environments and know-how for paper makers and paper converters own R&D and sales support.

3. Project structure, project parties and finance

AGRIPAP was a cooperation of VTT (TK5112, Biomaterial applications) and University of Helsinki (Department of Agricultural Sciences - Agrotechnology). The project was financed by Tekes (60%), VTT and UH (30%) and by private companies (10%). The private companies were Stora Enso, Walki, UPM, Kemira and Avagro. AGRIPAP started on 01.05.2010 and ended on 30.01.2014 (planned end date was 30.09.2013). AGRIPAP was executed in two parallel projects: VTT´s part of the study was carried out in AGRIPAP-lab –project and UH´s part in AGRIPAP-field project. Agripap-lab focused on development of manufacturing concepts of paper mulches. Agripap-field focused on testing of experimental mulch films and their mechanized laying in field conditions. Total budget of Agripap-lab and Agripap-field were 818 000 € and 724 000 € respectively.

Main tasks of Agripap-lab and Agripap fied are shown by Fig. 7. An essential part of AGRIPAP was the field tests of experimental paper mulches at experimental farms in Finland and abroad. Development of paper mulches in AGRIPAP-lab was based on the results and feedback from the experiments carried out in AGRIPAP-field. Three and a half year duration made it possible to test experimental paper mulches during three cultivation seasons and thus to make stepwise improvements in their performance.

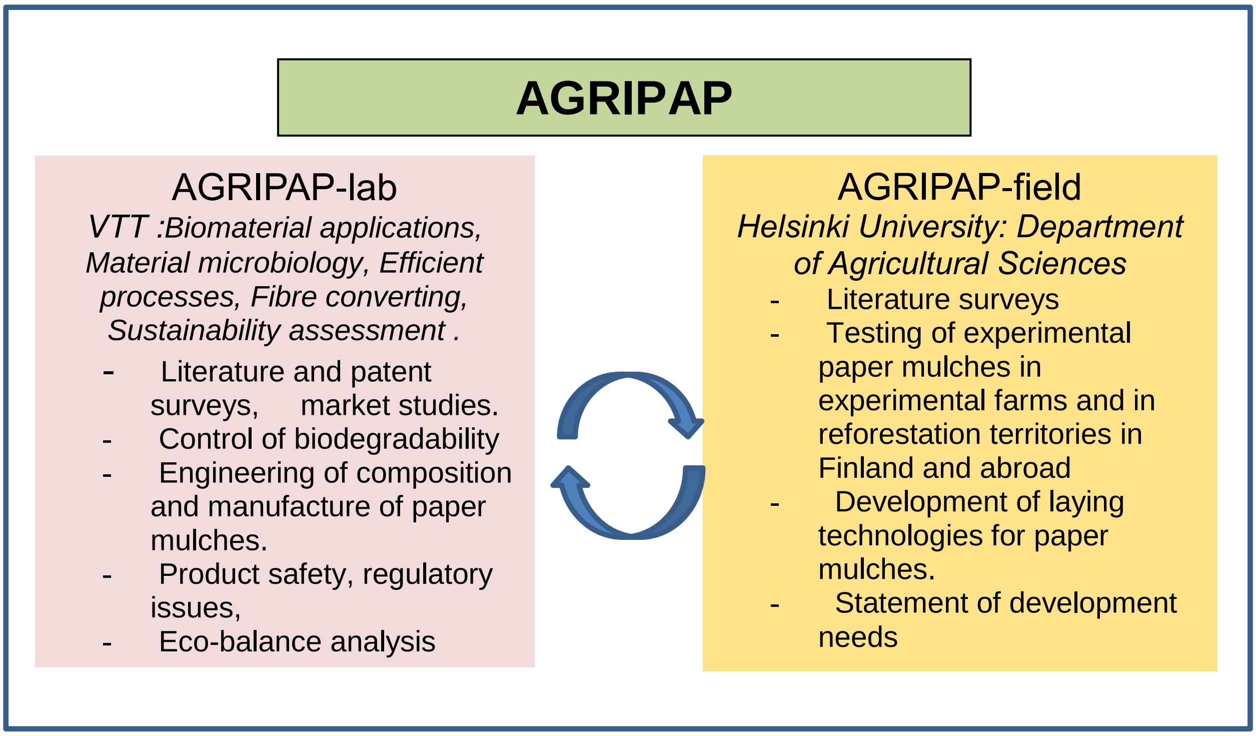


Figure 7. Layout of AGRIPAP: Development work in Agripap-lab was based on results of field trials carried out in Agripap-field.

4. First greenhouse and field trials - Facing up to development needs

Field- and greenhouse experiments carried out in Agripap-field during summer 2010 showed that conventional, slightly extensible papers like sack papers made from chemical pulps can be laid mechanically on the soil. However, the paper edges, which in mulching are buried under soil, degraded much too fast, i.e within couple of weeks. In order to be usable for mulching the edges should last the cultivation period, which is typically around 3 months, without extensive degradation. Otherwise wind can detach loose paper mulch from the soil (see Figure 8). On the other hand, papers made from chemimechanical or mechanical pulps showed much better resistance against biodegradation, but those papers were mechanically much weaker and tore very easily in the mechanical laying operation. (Fig. 9) After these observations the main challenges of Agripap were obvious: To develop paper mulches made from chemical pulp which has better resistance against biodegradation in soil, and, to develop paper mulches made from chemimechanical or mechanical pulp which are much more stress resistant than the conventional ones. Development work carried out in Agripap focused on those too objectives. Experimental paper mulches were made in laboratory-, pilot- and mill scale. The papers were tested in laboratory- , greenhouse-, and field conditions.

Figure 8. An experimental paper mulch of which the soil buried edges are degraded thereby allowing wind to tear the paper from the ground (Agripap-field, Viikki, 2011)

Figure 9. Breakage of non-extensible paper in mechanized laying.(Laitila, Avagro, Agripap-field, 2010).

5. Paper mulch development efforts

5.1 Improvement of stress resistance of paper mulches

Paper mulches designed for large area use should be stress resistant enough to withstand mechanical laying of the paper mulch on the soil. Also, the paper mulches should resist wind, rain and human working in the cultivations.

Field trials carried out in Agripap-field in 2010 and 2011 showed that extensible papers (sack papers) made from soft wood chemical pulps, the basis weight being 70 g/m^2 or more, are so stress resistant that they can be laid on the soil without severe difficulties using conventional plastic mulch film laying machines. Fluency of mechanized laying can be improved by proper adjustments of the laying machine, for example by adjustment of toe-in (wheel angle) of the machine (See Section 6.5). On the other hand, mechanical laying of papers made from mechanical pulps or chemimechanical pulps (90 g/m^2) was difficult or even impossible despite of treatments (clupak- or creping treatment) which made the paper extensible. In their case manual laying is the only option. The material strength of those papers is evidently too low for mechanical laying operation.

Increase of basis weight (g/m^2) of paper mulches would naturally improve their mechanical stress resistance. Use of that mean is restricted by the increase of paper mulch cost (€ / m^2) and the decrease of paper mulch reel length at fixed reel weight: Farmers usually handle mulch reels manually, which means that the weight of a single reel should not be much above 35 kg.

According to the field trials extensible papers, in general, are much easier to lay mechanically on the soil than non-extensible papers. When stressed, extensible paper elongate before they break. Such strong mechanical stressing which may break even very strong non-extensible paper takes place especially under and between the wheels of the laying machine (see Fig 10.) Extensibility of paper mulches made from soft wood chemical pulps should preferably be > 5 % in machine direction. This empirical finding of field trials is in accordance with statements presented earlier by Japanese researchers /18 /.

Figure 10. Mechanical laying of experimental paper mulch (H. Mikkola, A. Tamminen, UH, Viikki)

Paper can be converted extensible in its machine direction by clupak- or creping treatments. In Agripap-project experimental clupak treatments were carried out by Clupak AG and creping treatments by Walki. In clupak- or creping treatments there are no upper limits to the achieved extensibility. Normally, paper extensibility is increased in machine direction (MD) from 1-2 % to around 5-10 % and 20-40 % respectively. Cross directional (CD) extensibility of paper is mainly generated by the sheet shrinkage in CD and thereby depends to some extent on fibre orientation in the paper: The higher is the orientation in paper´s MD-direction the higher is its extensibility in CD-direction. Cross-directional extensibility can also be increased by allowing cross-directional shrinking of paper in paper machine drying section, but normally the means to control CD shrinking are limited. In the present study, unfortunately, the significance of cross-direction extensibility to stress resistance of paper mulches remained unclear. It´s plausible, however, that extensibility in both machine- and cross-direction are beneficial for fluency of mechanical laying of the paper on soil. Elongation of paper mulch in mechanized laying also helps the paper to settle tightly on the soil.

Clupak- and creping treatments make also mechanical laying on mulch papers made from mechanical and chemimechanical pulps easier. However, field experiments showed that such papers tend to lose their tension (relaxation) on the soil as the paper is moistened by water. The loss of tension exposes the paper to wind induced breakages and to formation of puddles on the paper mulch (Section 6.6). In the case of paper mulches made from chemical pulps no such problems come up.

Compared to softwood chemical pulps the advantages of mechanical and chemimechanical pulps are their lower price and especially their much slower biodegradation in the soil. They resist biodegradation in the soil long enough without any extra measures. However, their strength is insufficient for paper mulches which are laid mechanically on the soil. Not even increase of extensibility of the paper by clupak- or creping treatments make difference. Table 1 shows approximate minimum tear and tensile strength that extensible paper mulch intended for mechanical laying should have. The figures are based on experiences gained in the field experiments. None of the tested non-extensible paper could be laid mechanically on the soil (Agripap-field).

It is worth noting that paper mulches should withstand not only mechanical laying operation without breaking but also stresses caused by strong wind and working in cultivations. Observations of the field experiments indicate that paper mulches which can be laid mechanically on the soil resist also wind and work fairly well. However, conditions like windiness may be very different in different cultivations.

Table 1. Minimum tear (Elmendorf type) and tensile strength of extensible paper mulches intended for mechanical laying.

	Machine direction (MD)	Cross direction (CD)
Tear strength	> 800 mN	> 800 mN
Tensile strength	> 3 kN/m	> 3 kN/m

According to the experimental studies the most feasible way to improve tear strength of paper mulches made from mechanical or chemimechanical pulps is addition of long PLA- or viscose fibres into pulp mixture /19, 20/. Compared to other synthetic fibres the advantage of PLA- and viscose fibres is their biodegradability in the soil (Note: although PLA is often considered as biodegradable and compostable its decomposition in farm lands still needs to be assured). Even at relatively low proportions, with their high fibre length (in performed tests 6 mm), the synthetic fibres contribute to a significant increase of tear strength. With the highest tested proportion (20%) the increase of tear index in PGW based stock is 243 % with PLA and 177 % with viscose fibre. The positive effect of synthetic fibres on the tear strength is at least partially offset by the simultaneous decrease in tensile strength and tensile stiffness. The stretch at break remains unchanged. Thickness reduction of the synthetic fibres resulted in an increase of tear strength. The results of the experiments show that synthetic fibres can be used to increase the tear strength of papers made with mechanical or chemimechanical pulps. The effect originates in the high fibre length producing mechanically well entangled network, coupled with the high strength of the synthetic fibres. The gained tear strength (index) is well comparable to tear strength of softwood chemical pulps. Tensile strength, unfortunately, remains at significantly lower level (Fig. 11 and 12). The feasibility of synthetic fibre usage in paper mulches should still be tested by manufacturing the paper mulches in mill scale followed by mechanical laying of the papers on soil. The experimental papers should preferably be made extensible both in machine and cross-direction. Unfortunately, such an experimental arrangement could not be carried out in the present study.

During Agripap –project the participating companies made their own research and development work for manufacturing stress resistant paper mulches. The work included manufacturing and converting experimental paper mulches in mill-scale and testing the paper mulches in experimental farms. More information on those efforts can be enquired of the companies.

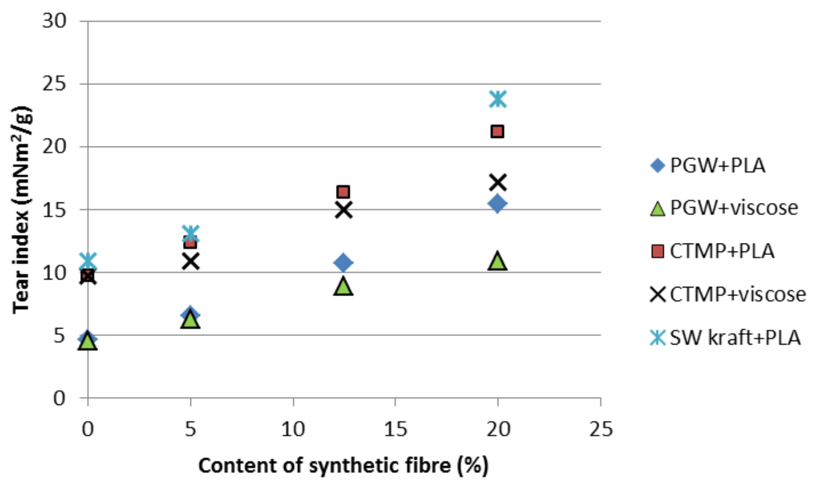


Figure 11. Tear index of the sheets made with a minor share of synthetic fibre . With PLA, the increase is 117% in CTMP and 243% in PGW stock, while with viscose fibre the respective increases are 77% and 141%. In softwood kraft, tear index increases by 118 % /19,20/

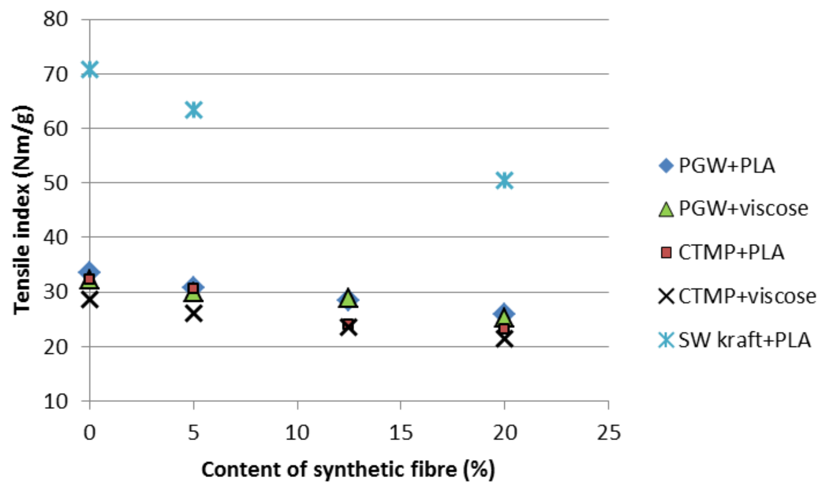


Figure 12. Tensile index of the sheets as function of synthetic fibre content, with PGW and CTMP the standard deviation ranges from 0.8 to 2.2 Nm/g and in SW kraft from 2.0 to 2.8 Nm/g. /19,20/.

5.2 Resistance against biodegradation in soil

Biodegradation of the experimental paper mulches in the soil was tested in laboratory and in greenhouse- and field conditions. In the used laboratory test, two types of soil mixtures from Viikki were used. Water holding capacity was adjusted by sand to 30-35% from the maximal capacity. Samples were attached to the plastic frames (5 cm x 5 cm) in which the area of the sample to be exposed was 3.5 cm x 2.3 cm. Three to five parallel samples were used for each test. Plastic frames were attached to steel frames which were buried inside plastic boxes containing the experimental soil mixtures (Fig 13). The boxes were incubated in controlled conditions (T= 21-24°C; humidity 55-60%) intending to simulate the field conditions. The water content of the soil was kept at the same level during the experiment by adding water in regular intervals. In certain intervals the frames were removed from the box and the degradability (degraded area) of the samples was evaluated visually (Fig. 14) /21/. The observations were compared to the results of the greenhouse tests and the field experiments (see Section 6). Although deviations of the results were rather large, especially in the case of greenhouse- and field trials, the results are logical and in accordance with each other. Used laboratory method seems to be a feasible tool for paper mulch biodegradation studies.

Figure 13. Biodegradation test arrangement /21/

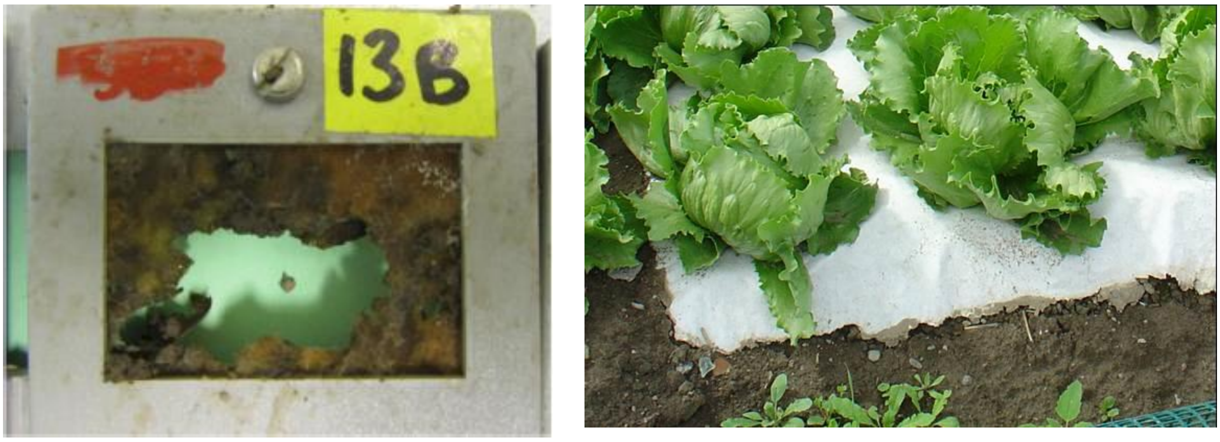


Figure 14. Biodegraded papers in laboratory (VTT) and in experimental farm (Viikki) / , /

According to the test results, the decay rate of the paper mulches in the soil is ruled by lignin content of paper making fibers: The lower is the lignin content the higher is the decay rate. The result is in accordance with earlier reported results /22/. Slow biodegradation of lignin is supposed to be due to its complex branched polymeric structure /23/. Paper made from chemical pulp fibres (sulphite- or kraf pulp fibers) contain very small amount of lignin residues. In the laboratory tests such papers biodegraded almost completely within 3-4 weeks. Papers made from mechanical pulp fibres (GW, PGW, TMP) or chemimechanical pulp fibres (CTMP) contain most of the native lignin of wood fibres (around 30 weight-%). Biodegradation of such papers takes around 3 months or more, which is long enough service time in most cultivation conditions. The observed biodegradation rates were quite the same in greenhouse and in field tests (Viikki). Addition of conventional paper making chemicals such as wet strength resin and hydrophobizing agent delayed decay of the papers somewhat, but not enough to tackle the main problem related to paper mulches made from chemical softwood pulps: They are strong enough for mechanized laying on the soil and can resist stresses caused by wind and rain and working in the cultivations, but the edges of the paper mulches buried in the soil biodegrade much too fast. Note: The severity of the problem depends on cultivations and their conditions. In Spain, where the climate and topsoil are drier (on average) the problem is not seen that pronounced /24,25/. Also, some of the cultivated plants like melon grow fast and are capable to hold the paper on ground despite of decay on the buried parts of the paper.

In order to delay the biodegradation of paper mulches – especially those made from chemical pulps – some special additives were tested. Prerequisites of the additives were as follows: The additive must be abundant for papermakers, environmentally safe in every way, and reasonably low cost. The tested additives and the results were as follows:

- Sulphate lignin (Indulin AT): The idea was to test if an addition (5 weight-% and 30 weight-%) of Indulin AT (WestVaco) in paper is capable to delay degradation of the paper in the soil. Induline AT sulphate lignin resembles closely native lignin. It is dark-brown coloured substance and could also act as a colorant in paper mulches. Indulin AT was added into paper in a precipitated and in a powder forms. The results showed no significant effect on the biodegradation rate of the tested papers. Added lignin seems not to be capable to protect fibres from biodegradation in the same way as native lignin does.

- Acidic minerals: Optimal pH for bacterial and fungal activities have been reported in the ranges of 6 – 7,5 and 5,5 – 8,9, respectively. Below pH 5 the microbial activity is limited /23,26/. The idea was to test if biodegradation of paper in soil can be delayed by adding acidic minerals into paper i.e. minerals that are capable to lower pH of paper buried in the moist soil. The added minerals were ground pyrite (FeS_2, av. particle size 13,8 µm), which liberates H^+ through reactions with oxygen, and two industrial waste gypsums, one containing sulphuric acid residues and another containing phosphoric acid residues. Average particle sizes were 2,6 µm and 5,5 µm respectively. The average content of the minerals were in a range of 13 weight-% to 23 weight-% in papers. Unfortunately, no clear effect on the decay rate of the papers in the soil was observed. The actual pH of the papers in the soil could not be measured.

- Formates: It is known that formates are capable of preserving wood from microbial attacts /27/. The weak point of formates is their water solubility making the protective effect in wood temporary. In the present study it was tested if formates could delay biodegradation of paper mulches in the soil. For the examination, experimental paper mulches made from chemical softwood pulp, TMP and CTMP were impregnated with 6 different concentrated formate solutions delivered by Kemira. After the impregnation the papers were dried and tested. None of the formate solutions had significant effect on the biodegradation rate. It may be, that in the moist soil the formates are rapidly diffused from the papers into the soil.

Experiments carried out in cooperation with Stora Enso showed, that thermo wood treatment (Thermo-S process), which improves biodegradation resistance of timber, improves also biodegradation resistance of PGW, CTMP and corrugated boards /21/. After 1 year burial in soil no biodegradation of the samples was observed. The method could be used for manufacture of long lasting (> 1 year) mulch sheets. Such sheets could find practical use in cultivation of perennials and in forestation (see Fig. 15). Experiments carried in AGRIPAP-field showed, that the main problem of the paper board mulch sheets is their tendency to curl up on the soil (see Section 6.7).

Figure 15. Paper board mulch sheets in forestation use. Agripap-field test site in Pieksamäki.

During AGRIPAP, industrial partners of the projects continued their own development work for improved biodegradation resistance of paper mulches made from soft wood chemical pulps. More information on those achievements can be gained directly from the companies.

6. Performance of experimental paper mulches

6.1 Field test sites

<u>Finland</u>

Field tests of agricultural papers and laying machines were done in Finland mainly at the University of Helsinki in Viikki. Besides this, some experiments were also done at Finnish Beet Research Center (Sokerijuurikkaan tutkimuskeskus). Viikki is situated in Southern Finland (latitude, 60°13'N; longitude, 25°01'E. The objective of the growing tests was two-fold: testing of the paper degradability and comparing the papers to biodegradable plastics in regard to plant yields. Growing tests were done with cucumber and maize. Figure 16 shows the growing experiment test field in Viikki.

Figure 16. Viikki growing test field

In the first year (2010) only the degradability of the papers was tested (Fig.17). The test weather was recorded with a weather station and the soil temperatures and moisture contents were measured with soil moisture and temperature sensors (Decagon Devices). The data was collected with a data logger. The same instrumentation was used also during the following years in growing tests.

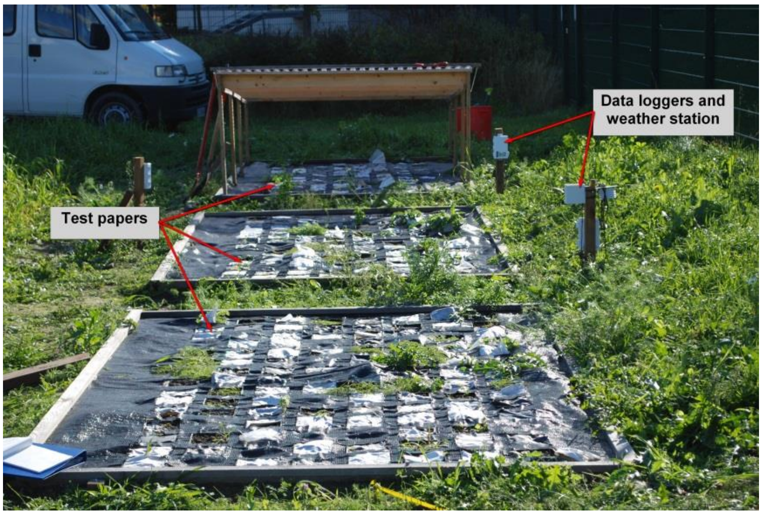


Figure 17. Degradation tests in Viikki in 2010. The papers had three different weather treatments and in the fourth treatment the papers were buried into the soil.

In 2013 tests the laying machine was modified so that pressing wheels were replaced with brushes. Also earthing of the benches was experimented. The papers degrade first from edges which are in contact with soil. With earthing the edges are covered again with soil, which prevents the wind problems.

Tests abroad

Beside borealis circumstances, tests were also performed in warmer and dryer climates in Turkey Adana, Spain Zaragoza and Swaziland Mbabane. In Turkey the tests were done in collaboration with Cukurova University, Department of Agricultural Machinery. The paper experiments were done on water melon fields near Adana city (37.0000° N, 35.3213° E). Figure 18 shows an example of the experiment in 2013. Paper mulch tests were performed in Turkey in 2011 – 2013. The first tests were small scale paper tests similar to those carried outin Viikki (Figure 17). In 2012 and 2013 full size paper mulches were tested in normal field conditions. The tests were done during March – June in water melon cultivations. Usually mulches are used for melon growing in Turkey. The weather data and also soil temperature and moisture contents were recorded during these experiments. In 2012 the planted melons germinated poorly and the vegetation grew slowly. The paper edges in contacti with soil degraded fast and, due to the lack of vegetation, wind spread papers. In 2013 experiments the papers were laid on the melon bench and the bench was covered with plastic tunnel, which warms the soil and prevents frost. The plastic is collected from the field when the ambient temperature is warm enough. This method prevents the wind problems with papers.

Figure 18. Agripap field trials in Adana,Turkey. The papers are laid on the water melon benches and they are covered in the beginning of the growing season with plastic tunnels (A. Ince).

Agrifood Research and Technology Institute of Aragon (CITA = Centro de Investigacion y Technologia de Aragon) is situated in Zaragoza Spain (41.6500° N, 0.8833° W). The institute has done paper mulch research for several years and they have their own established paper mulch research field. They do the experiments mainly with pepper plants. Agripap mulching papers were tested together with CITA own test papers during summer 2013 (Fig. 19) /32/.

Figure 19. CITA paper mulch experimental field.

Papers were also studied in Swaziland Mbabane (26.3167° S, 31.1333° E) in subtropical conditions together with Baphalali Swaziland Red Cross Society. Figure shows the experimental field in Swaziland. This test was done between the end of year 2012 and beginning of year 2013 (Fig. 20).

Figure 20. Paper mulch experiment in Swaziland.

In Table 2 the test places and different tests are summarized.

Table 2. Summary of paper mulch test places and tests

Time	Place	Test description
Summer 2010	Viikki Finland	Paper degradation tests with different paper types
Winter 2011	Adana Turkey	Paper degradation tests with different paper types
Summer 2011	Viikki Finland	Laying machine tests, cucumber and maize growing tests with different paper types and biodegradable plastic
Winter 2012	Adana Turkey	Water melon growing tests
Summer 2012	Viikki Finland	Laying machine tests, cucumber and maize growing tests with different paper types and biodegradable plastic
Autumn 2012 and winter 2013	Mbebene Swazilan	Butternut benches with four different paper mulches.
Winter 2013	Adana Turkey	Water melon growing tests with different paper types in plastic tunnels
Summer 2013	Viikki Finland	Laying machine tests with brushes, earthing of benches, cucumber and maize growing tests with different paper types and biodegradable plastic
	Piikkiö Finland	Paper use in beet growing
	Zaragoza Spain	Paper laying tests and paper type tests with pepper

6.2 Moisture and temperature of soil

The warming of the soil is really important in the beginning of the growing season because, if the plants grow faster than usual, the farmers get earlier yields from the plants and thus a better price for their products.

Soil temperature and moisture was measured with sensors at 10 cm depth in Finland in three consecutive years. In 2011, kraft* paper that was coated on both sides with a biodegradable film was the warmest of all mulches during the whole summer. Black kraft papers (MIMGreen and UPM WEX WS printed black) have warmed the soil almost as much as black biodegradable plastic mulches used in the trials. During the first few weeks the warming of the soil has been the highest with transparent paper mulches.

As the cultivated plants grow and the leaves start to reduce the amount of solar radiation that gets to the surface, the warming effect of the mulches diminishes (Fig. 21 and 22).

** Kraft paper = paper made from softwood chemical pulp*

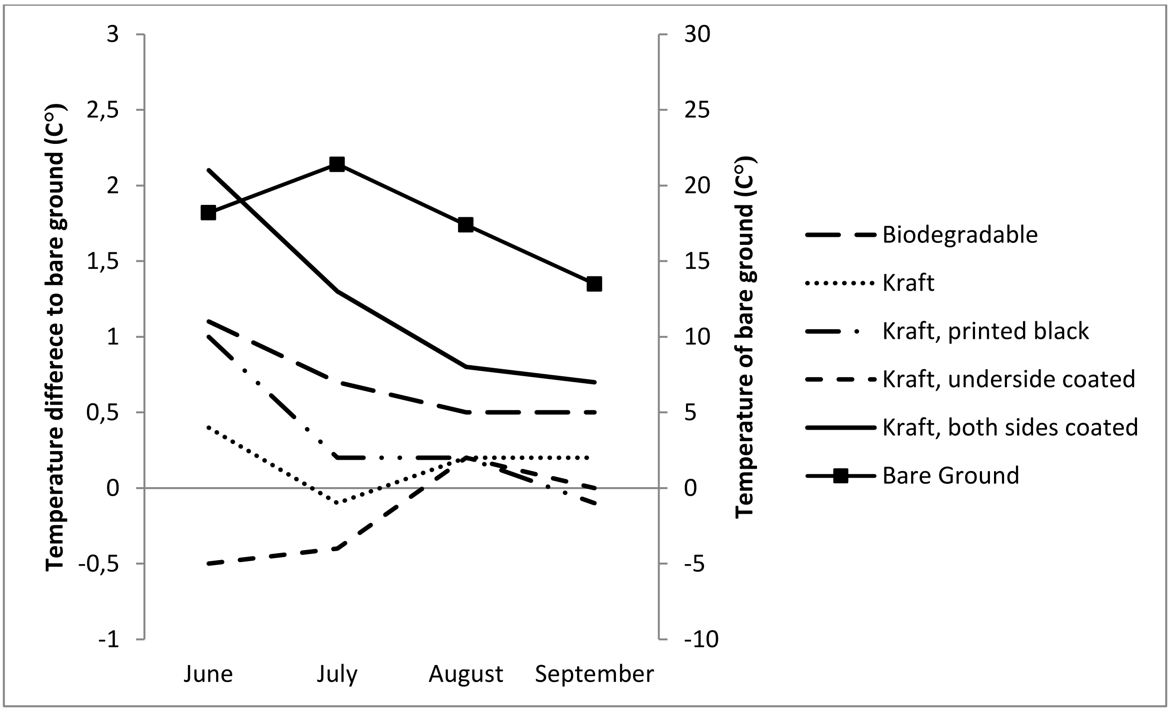


Figure 21. Temperature differences to bare ground at 10 cm depth in 2011.

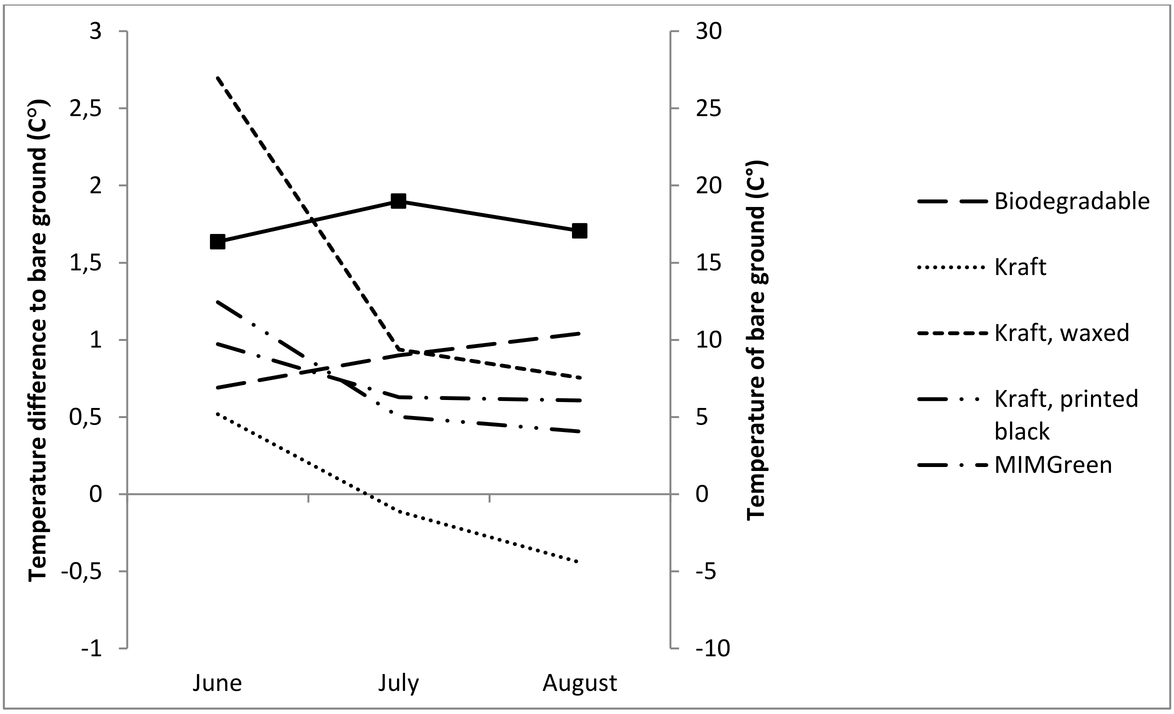


Figure 22. Temperature differences to bare ground at 10 cm depth in 2012.

The soil moisture at 10 cm depth was not affected by the mulches as irrigation was used to ensure good growth. However, it was observed that plastic mulches did retain moisture of the soil surface from the irrigation somewhat better than non-coated paper mulches because of their inability to breathe. In general, use of mulches reduces need of irrigation. Type of the mulch (plastic vs. paper) does evidently not have significant effect on the demand of irrigation.

6.3 Prevention of weed growth

One of the main reasons to use mulches in agriculture is to limit the growth of weeds. Many previous studies have found that paper mulches are as good in preventing weed growth as polyethylene mulches in general. Also some studies suggest that paper mulches are better than polyethylene mulches in preventing the growth of Purple nutsedge which is considered to be one of the worst weeds in the world /31/.

In order to prevent the growth of weeds the mulch has to absorb or reflect photosynthetically active radiation (400-700 nm). An effective way to increase the absorption is one-side printing of the paper by black colorant. All black coloured papers and all papers made from mechanical pulp prevented the growth of weeds under the mulches in all trials reducing the need to weed or to use herbicides. Some weeds did grow out from the planting holes, but this happens with plastic mulches as well.

Wax and oil treated papers were more light transparent allowing the weeds to grow under the mulches and to lift the mulches up making them prone to wind damage (figure 23). This problem was observed in Finland, Turkey and Spain. However the amount of weeds under the waxed and oiled papers was much less than in bare ground treatments.

Figure 23. Weeds lifting waxed kraft paper.

6.4 Amount and quality of yield

In Finland the effects of mulches to the yield of Cucumber was measured in three consecutive years. Every year all the mulches increased the yields when compared to bare ground. Commercial biodegradable plastic (Bioska) was used as a reference each year. During the first year the highest yield was from the plots with the kraft paper that was coated on both sides with a biodegradable film. Other kraft papers yielded more or less the same as the biodegradable film with the brown untreated kraft being the weakest. In 2012 all the paper mulches yielded pretty evenly while the biodegradable plastic had the highest yields

Table 3. Cucumber yields from field trials

	Yield in 2011 (kg/m^2)	Yield in 2012 (kg/m^2)	Yield in 2013 (kg/m^2)
Bare ground	10	4.3	4.1
Biodegradable plastic	14.7	9.1	9.9
Kraft	12.3	8.2	
Kraft, printed black	14.6	8.3	8.9
Kraft, underside coated	13.6		
Kraft, both sides coated	15.9		
Kraft, waxed		8.0	
MIMGreen		7.9	
Stora Enso OneSeason			7.5
Kraft, oiled and black colour			7.8
Kraft, oiled			8.4

In Turkey (2013) watermelon was grown on a commercial field with plastic tunnels in the beginning of the cultivation period to prevent the seedlings from suffering from cold. In the yields there was no noticeable effect from the mulches as the yields from bare ground were as high as the best mulches (paper and plastic). One reason for this could be the warming effect of the plastic tunnel used in the beginning of the season. However the mulches prevented the growth of weeds and thus weeding was not needed in these plots, making the growing less laborious.

In Spain (2013) experimental paper mulches were tried along with commercial polyethylene mulch, three different biodegradable plastics and one commercial paper mulch (MIMGreen). After two harvests the paper mulches have produced equally or more tomatoes than polyethylene and biodegradable mulches. The final results after the third harvest are still to come.

Mulches help to maintain good fruit quality especially with plants that grow on top of the surface e.g. cucumbers and melons as the fruits aren't in contact with soil. In Spain (2013) there was no noticeable difference in the amount of rotten fruits when using paper or plastic mulches in contrast to bare ground.

6.5 Mechanical laying

Mulch can be laid on soil surface by hand or with a mulch laying machine. Mulch laying machines are used in developed countries where labour costs are high compared with investments in mechanical laying, or if it is difficult to get labour for agricultural work like this. A mulch laying machine is an implement which is coupled to a tractor and used to lay a thin mulch (< 1 mm) to cover soil surface (Fig. 24). Mulches made of polyethylene are mostly used. In general, the laying machine lays mulch on one 0.6 – 1.2 m wide plant row or soil bed at one pass but there are on the market machines which can lay mulch for three plant rows at one pass. One laying machine makes the same work as dozens of workers and the quality of the work is better than that of handwork. The good work quality means that mulch is stretched and placed firmly against compacted soil (on a curved soil bed or on flat soil) and edges of mulch are properly buried under soil, so, that wind can't loosen them. Soil compaction is necessary because planting holes are made by punching the mulch film with an edge. If there is loose soil under mulch the edge only stretches mulch resulting to very small holes or no holes at all. Equipment for making planting holes is an accessory likewise equipment for planting seedlings into the holes, equipment for placing a drip irrigation hose under mulch, or equipment for placing fertilizer under the soil bed so that plant nutrients are exactly in the root zone available for plants.

Mechanized laying demands that soil is free from stones and crop residues because they easily clog the machine. Furthermore, soil has to be tilled properly into the depth of 10 – 15 cm. Making a good formed soil bed is not possible if the soil is compacted or the texture of the soil is coarse (a lot of soil particles > 5mm). The required tillage depth depends on the size of the soil bed. The bigger the bed has to be the deeper soil has to be tilled. If mulch is laid on flat soil the tilled soil layer can be only 5 – 10 cm. Light sandy and organic soils suit better for mulch laying than heavy clay soils because it is easier to till a fine texture into light soil. Soil particles bigger than 5 mm in diameter make the soil surface uneven, making it more difficult to place mulch firmly against soil surface. Burying the edges under soil can cause problems if the soil texture is course. Flat soil topography is an advantage for mechanical mulch laying because differences in elevation make it difficult to keep the wanted spacing between adjacent soil beds.

Figure 24. A standard Rapi laying machine (Avagro Oy) laying successfully mulch made of sack paper

A standard Rapi mulch laying machine was used in the field tests (Figure 24). The standard machine was used because it would be an advantage for farmers if plastic and paper mulches could be laid with the same machine. Construction of the Rapi laying machine is presented in figure 25 and the machine operates as follows. In front of the machine there are outer and inner coulters (2 pieces of each, left and right) which move loose soil from the width of about 1.2 – 1.4 m to a 0.6 – 1.2 m wide bed. Behind the coulters there is a roller which compacts soil and forms the soil bed. If the soil bed is not needed the coulters can be removed or the head of the machine is elevated so that the coulters do not touch the soil. In the lower right part of the figure 25 there is a small wing coulter, which makes a 5 – 10 cm deep and 10 cm wide groove into soil for burying the edge of mulch into soil. A press wheel presses the edge of mulch to the groove and a covering disc throws soil on the edge. The press wheels (2 pieces, left and right) are adjusted so that they stretch mulch sideward over the soil bed (toe-in). Behind the rear end of the mulch roll there is an adjustable disc brake (not visible in the figure 25). It prevents the mulch roll from rotating free when the tractor stops and makes possible to stretch mulch in the direction of travel. At the end of the laying machine there are wheels which support the rear end of the laying machine. The head of the machine is supported with lower links of the tractor. The frame of the Rapi laying machine is adjustable for mulch widths from 100 cm to 140 cm. In general, two workers are needed to operate the machine. One worker operates the tractor and another assists in laying by covering the ends of mulch with soil at headland, controlling laying and changing mulch rolls.

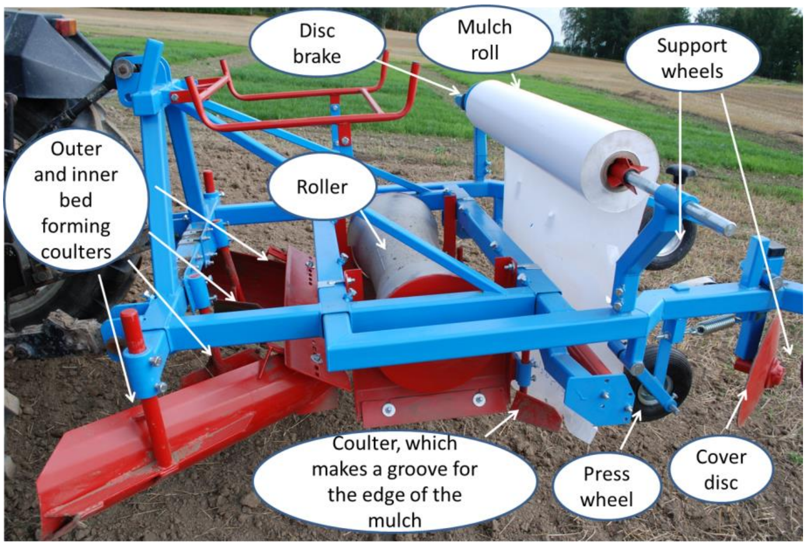


Figure 25. Construction of the Rapi mulch laying machine (Avagro Oy).

Results of laying tests on field

The aim of the field tests was to study whether a standard laying machine can be used for laying paper mulch. Laying machines are planned for laying plastic mulch which is of different quality than that of paper mulch. It was known in advance that tear and tensile strength of plastic are higher than that for paper mulch with basis weight of 60 – 100 g/m^2. Plastic is also more elastic than paper which is an advantage in mulch laying.

Paper mulch stood mechanical laying on soil bed without tearing if tear strength was > 800 mN and tensile strength > 3 kN/m. Paper mulches with lower tear and tensile strengths could be lied on flat soil without noteworthy tearing but when laid on soil bed they tore so badly that laying interrupted constantly and due to many tears mulch was vulnerable for further tearing caused by wind. A typical tearing point located in front of the press wheels in a place where mulch was forced from horizontal position under press wheels. The orientation of the tears was more random than typically transversal or longitudinal. However, some creped paper mulches tore mostly in the longitudinal direction.

Paper mulches with low tear and tensile strength were sensitive for tears caused by wind. Tearing started mostly from planting holes (Fig. 26). They were made with a four edged punching tool (Fig. 24). From Fig. 26 it can be seen that paper mulches on the left and right side of torn paper mulch (in the middle) have not torn although planting holes were made with the same punching tool. Round planting holes would perhaps prevent wind tearing but a more advanced tool would be needed for doing them or the holes should be done in advance. Sometimes birds pecked holes into mulch and these holes can be starting points for wind tearing, too. It can be concluded that the mulch must have certain strength in order to stand the stress of mechanical laying and this strength is needed later on to prevent tears caused by wind.

Figure 26. Tears caused by wind in the middle row. Planting holes induced tearing if the strength of mulch was low.

Hilling up the edges of mulch

Fast decomposition of the edges of paper mulch causes the problem that mulch is not any more anhroed to soil. Wind can throw loose mulches away or mulch flapping in wind can injury growing plants. One solution to solve this problem would be to raise more soil on the edges if the decomposting has advanced. An old sugar beet hoe was modified for this purpose. Tines of the hoe were removed and two heavy duty cultivator tines were installed to the frame (Figure 27, left side). Edges of mulch were hilled up with the hoe and this operation helped to keep mulch anchored in soil longer. Hilling has to be done before the plants are so high that the tractor or the hoe would injure them. Working speed can be 6 – 15 km/h depending on field conditions. In the case of the figure 27 soil was hard and dry clay soil but the edges could be hilled up successfully anyway.

Figure 27 A modified sugar beet hoe for hilling up the edges of mulch (left). A row of maize which has been hilled up with the modified hoe (right).

6.6 Weather resistance

The conditions in the field can be quite harsh for the paper mulch. Paper mulches tend to gather moisture during the night if the relative humidity is high enough and also the evaporating moisture from the soil keeps the lower surface moist. Solar radiation dries the mulch during day time and this constant moisture changes can cause the paper to tear or to wrinkle. During the field trials in Finland it was observed that untreated kraft paper would tear horizontally every 10-15 meters after a few days in the field because of the shrinking (Figure 28). This occurred even without rain as the papers dried during the day.

Figure 28. Tearing caused by shrinkage (UPM WEX WS)

Creping the paper eliminates the tearing of the paper caused by shrinkage. Kraft paper held the creping really well, but PGW based papers had the tendency to lose the creping (relaxation) and they became lose and prone to wind damage and pools of water formed on top of the papers (figure).

Figure 29. Pools of water on top of a creped paper.

Once the soil covered edges start to degrade, the paper mulch is more susceptible to wind damage. Even a small area that is not intact anymore can cause the whole mulch to be blown away by the wind.

Coating the paper with biodegradable plastic to hinder the degradation was also tried during the project. The coating peeled off in 2 to 4 weeks, leaving small pieces of biodegradable plastic all over the field (Fig 30.)

Figure 30. Biodegradable plastic film coating peeling off after two weeks.

6.7 Paper board mulches

The endurance of paper board mulches made from PGW and CTMP were studied in Finland. Thermo wood treatment made the boards more prone to break from bending or to tear, but also increased their resistance to biodegradation (figure 31).

A cut was made to the boards from one edge to the middle to help to place the boards around the planted Birches. Untreated boards curled upwards along the cut line due to moisture differences of the bottom and surface (Fig 31).

Figure 31. On the left: heat treated PGW board broken during installation. On the right: PGW board with the cutting line curled up and weeds growing through.

All the boards (with and without thermo wood treatment) effectively blocked the growth of weeds except the ones where the curling had occurred.

After one year the PGW boards had degraded the most, but the heat treated boards were more or less intact (Fig. 32).

Figure 32. PGW board after one year. Weeds have penetrated the board.

Figure 33. Heat treated PGW board after one year.

The boards need to be anchored to the ground somehow and two different approaches were tried. The first method was to shovel dirt on top of the edges of the boards. This worked really well to hold the boards in place for over one year period, but it is extremely laborious and most likely not an option in commercial scale forestry. The second method was to use steel hooks in the corners of the board. As the thermo wood treatment made the boards more fragile, the hooks weren't a good option in a windy place as the wind got under the curled boards and the boards tore easily from the edges and flew away. Also if the weed pressure is high, the boards might get lifted up by weeds.

Some kind of a biodegradable, e.g. wooden, nail with a large flat head would most likely work well to anchor the boards firmly to the ground and to reduce the risk of the boards flying away. The boards were too small in size (60 cm x 60 cm) to cover a large area enough to help the tree seedlings to grow without the competition from weeds.

6.8 Development needs

6.8.1 Paper mulch properties

6.8.2 Mechanized laying

Tearing of paper mulch was the main problem of the laying work. Tearing took place especially in front of the press wheels. For this reason trials were made to reduce stress in the mulch by modifying the machine. The pressing wheels were replaced with nylon brushes and the idea was that brushes don't stress mulch as much as wheels because brushes are flexible compared with wheels and mulch can turn from horizontal position under brushes at longer distance. Friction between nylon brushes and paper mulch was assumed to be lower than between the rubber wheels and mulch. It was assumed also that brushes press mulch against soil so firmly that folding could be avoided. Nylon brushes installed instead of the press wheels are presented in Figure 34. They reduced tearing but did not stop it. A new problem occurred due to the low friction between brushes and mulch. Though the position of brushes, their angle and their pressure against mulch could be adjusted, versatile brushes could not stretch mulch so that folding would have been avoided. Tearing remained a problem especially when paper mulches were laid on the soil bed.

Figure 34 Press wheels replaced with nylon brushes

7. Carbon foot-print of paper mulches

Sustainability of different mulch materials can be estimated by calculating their carbon foot prints taking into account the whole life cycle of the materials, and by rating harmful environmental effects of their use in agriculture such as pollution of farmlands, rural environments and water systems by non-biodegradable plastic mulch waste. As there are no generally accepted standards for rating of such environmental effects the study focused to carbon foot print calculation.

The carbon foot print calculation concerned three different hypothetical paper mulches (thermo-mechanical-pulp (TMP) –based paper, softwood pulp (SW) –based paper, and chemi-thermo-mechanical-pulp (CTMP) –based paper), three different polyethylene mulch films (low-density polyethylene (LDPE), high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE)) and one biodegradable plastic mulch film. Carbon footprints were calculated using cradle-to-grave –approach, which means that the whole life cycle from the raw material acquisition to the disposal/degradation of the mulch material was taken into account /29/.

As usual, the results of the carbon foot print calculations are influenced by manifold variables and assumptions regarding their default values. However, on the basis of the calculations it seems that there are no substantial differences in carbon foot prints of PE-mulch films, biodegradable mulch films and paper mulches (see Fig. 12). The climate change effect of using the different mulch types are of the same magnitude. Paper mulch made of soft wood chemical pulp and polyethylene mulches have the lowest carbon footprints with the made assumptions /30/. It is evident that regarding the overall environmental impacts the chief asset of both biodegradable mulch films and paper mulches is their biodegradability and thus the absence of plastic film waste accumulation in the cultivated land and environment.

In order to assess the overall environmental impacts or the sustainability of mulches, a wider and more detailed assessment with e.g. effects on yield rates, soil structure, soil contamination with plastic and economic aspects should be considered.

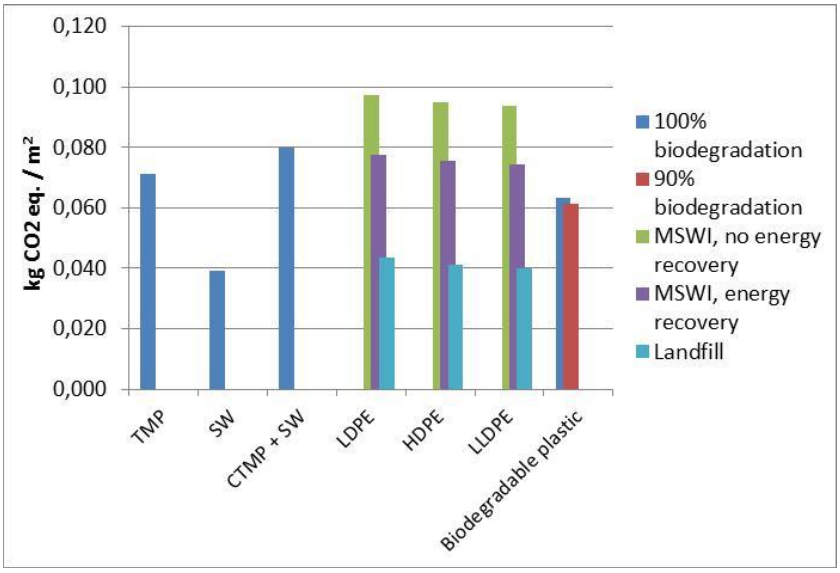


Figure 12. Carbon footprints of hypothetical paper mulches made from theromechanical pulp (TMP), softwood chemical pulp (SW) and chemimechanical pulp CTMP+SW xx%, and plastic mulches (LDPE, HDPE, LLDPE) per square meter (m^2). For PE mulches, landfill treatment is the most realistic disposal option.

8. Safety aspects of paper mulches

So far, no safety regulations or recommendations regarding composition of paper mulches exist yet. The main objective of the safety aspect study carried out in AGRIPAP was to bring out other regulative issues and general recommendations which later on may indirectly influence admissibility of paper mulch use in agriculture /30/.

A good guideline for paper mulch developers is technical report CEN/TR 15822 “Plastics. Biodegradable plastics in or on soil. Recovery, disposal and related environmental issues”. The document is intended to provide a basis for the development of future standards. Although the technical report concerns plastics which are used on soil or end up in soil the safety criteria are evidently relevant to paper mulches too. Adapted to mulch materials the criteria are as follows: A) Mulch material added into soil must convert to CO_2 and biomass quite rapidly to ensure that material or its fragments do not accumulate in soil during the time. B) Mulch material or its degradation products must not be toxic to environment or to humans. They do neither influence negatively the germination of seeds or yield of crops. In addition there must not be unacceptable environmental impacts on air, water or soil, C) Proof of biodegradability of mulch material must be based on measurements done in conditions which simulate real field conditions.

At present, there is no standardized method for test of biodegradability of mulches. The European Standard EN13432 "Requirements for packaging recoverable through composting and biodegradation - Testing scheme and evaluation criteria for the final acceptance of packaging", defines the characteristics that a material must have, in order to be defined as "compostable”. The standard sets limits for volatile matter, heavy metals (Cu, Zn, Ni, Cd, Pb, HG, Cr, Mo, SE, As) and fluorine. The testing conditions of biodegradation specified by EN13432 are unfortunately not realistic regarding biodegradation of mulch in soil: The testing temperature which simulates industrial compost temperature (above 60 °C at least for one week and above 40 °C for four weeks) is much higher than typical soil temperature in cultivations. This may lead to mistaken results regarding biodegradability of different mulches in soil. Certificates such as *Vincote OK composts (home)* and *Vincote OK biodegradable (soil)* are based on EN 13432, however, the testing temperature is more realistic (20 – 30 ^{o}C)

Criteria and guidelines of organic food production are not yet fully established and harmonized. They generally exclude or strictly limit the use of herbicides, insecticides and fungicides in organic food production. According to most criteria, also substances produced from GMO maize or other GMO plants are not accepted in organic food production. When launch of paper mulches for organic food production is considered, it is worthwhile to check updated criteria of organic food production in different market areas.

In Europe protection of human health and the environment from pollution caused by chemical substances is implemented by REACH regulation. The regulation stipulates substances as such, in mixtures and in articles. Under the regulation paper mulches are considered as articles i.e. “as objects which during production are given a special shape and surface which determines its function to a greater degree than does its chemical composition”. In the REACH regulation chemicals and substances of very high concern (SVHC) are listed. SVHCs include chemicals that are carcinogenic, mutagenic, toxic to reproduction (CMR) or those having persistent, bioaccumulative and toxic properties (PBT) or very persistent and very bioaccumulative (vPvB) properties. It is evident that such harmful chemicals or substances are not acceptable constituents of paper mulches. Paper mulch safety risk analysis is justified if some special raw materials or chemicals such as fungicides are used as additive in paper mulches.

According to criteria of compostability standards EN13432 and certificates (for example Vincotte OK biodegradable SOIL,) the amount of single non-biodegradable man-made substances, like some polymeric bonding agents, should not exceed 1,0 weight-% in mulch materials. Total amount of such material must not exceed 5 weight-%.

9. Launch of new paper mulches

Launch of paper mulches is in many ways a challenging task to papermakers. Regarding the required product properties and the end use, no other paper product comes close to paper mulches. The end product requirements (customer needs) are fractured by cultivation conditions. Price competitiveness of paper mulches depend on the prices of biodegradable mulch films, PE-mulch films, as well as labour and landfilling cost which may be very different in different countries and regions. When considering the launch of paper mulches papermakers have to consider at least the following issues:

- Sales areas / type of cultivations – where to start?
- Creation of the sales network, sales- and customer support and training of sales men.
- Logistics of the paper mulches (mulches are seasonal articles)

Tackling of the issues is surely a big challenge and effort for papermakers. On the other hand, low cost biodegradable mulch is something farmers would like to use in farming. In testing sites in Finland, Spain and Turkey it became evident that farmers are very willing to test paper mulches in their cultivations. It is also possible that in some countries like Spain use of non-biodegradable mulch films will be restricted or totally prohibited by law. Mulch film market expert Carla Vittova noted in Agricultural Film 2013 conference, that it can be hard to get into mulch film business, but on the other hand, demand of the biodegradable mulches may be huge in the future.

10. Concluding remarks

AGRIPAP focused on development of environmentally friendly, low cost paper mulches which could replace presently used plastic mulch films in agri- and horticulture. It was discovered early in the project that the primary development needs of such paper mulches are the improvement of mechanical strength and the biodegradation resistance of paper mulches. Accomplishment of those development targets is a prerequisite for success in the mulch markets. In the future development targets may be different relating to added functionality of paper mulches. Second generation paper mulches may contain ingredients like environmentally friendly plant protectants, controlled release nutrients and optically active pigments. In ongoing DF-Trap project (Development of cost-efficient dew and fog collectors for water management in semiarid and arid regions of developing countries, 2013-2017) financed by Academy of Finland, VTT and UH (Departments of Agrotechnology and Physics) are developing paper mulches which are capable to absorb large amounts of water (dew) from the air and move it to use of cultivated plants or tree seedlings. VTT and UH Agrotechnology are also seeking funding for a study which would focus on use of paper mulches for soil erosion control. Due to limited resources the subject had to be left out from AGRIPAP.

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