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Paper Based Mulches as an Alternative to Polyethylene Mulch in Vegetable Production

Jukka AHOKAS[1], Antti KORPELA[2], Ahmet İNCE[3], Emin GÜZEL[3], Jaakko ASIKAINEN[2], Tapani HAAPALA[1], Marjukka KUJANPÄÄ[2], Hannu MIKKOLA[1], Marja PITKÄNEN[2], Antti TAMMINEN[1], Minna VIKMAN[2]

[1] University of Helsinki, Department of Agricultural Sciences,
P.O.Box 28, FI-00014 University of Helsinki, Finland
[2] VTT Technical Research Centre of Finland, Biomaterial applications, Espoo,
Biologinkuja 7, FI-02044 VTT, Finland
[3] Çukurova University, Faculty of Agriculture, Department of Agricultural Machinery,
TR-01330 Balcali-Adana, Turkey
hannu.j.mikkola@helsinki.fi

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Abstract: This paper presents results of the AGRIPAP-project which aim was to develop a low cost, well performing paper mulch as an alternative for plastic mulches. Plastic mulches are predominantly made from polyethylene (PE) which is of fossil origin and it is non-biodegradable. Plastic mulch should be removed from the field after cultivation period in order to avoid mulch accumulation into soil. Due to contaminants, like soil and plant residues, waste plastic can’t be recycled but it has to be disposed in a landfill. For paper mulches, the same agricultural advantages were aimed for as those of PE mulches i.e. high yield, good yield quality, low demand for weeding, and sufficient resistance of weather conditions.

The study was started by screening paper qualities suitable for mulching from a group of 32 candidate papers. Their mulching properties were tested in laboratory tests and papers were compared in field trials with biodegradable plastic, PE mulch and bare soil. The most promising paper qualities were chosen to further studies. Additives to control their biodegradability, properties in mechanized laying, impact of mulch quality (composition, color, transparency) on weather resistance, weed growth, soil temperature, and soil water content were also studied.

Field experiments carried out in Finland, Turkey, Spain and Swaziland indicated that the best paper mulches performed comparably to conventional PE mulches and biodegradable plastic mulches in terms of yield, weed control, and resistance of weather conditions. Paper mulches can be mixed into soil after growing season and they don’t accumulate into soil but they are decomposed.

Key words: mulch, polyethylene, paper

INTRODUCTION

Plastic mulch films are used in vegetable, berry, and fruit cultivation to prevent weed growth, to control temperature and soil moisture, and to prevent water and wind erosion (Haapala et al. 2014). In large scale cultivation plastic mulches are laid on soil mechanically while hand-laying is used in home gardens. Hand-laying can be also used in large scale cultivation if labor is available at a reasonable price.

Typically, use of plastic mulch in contrast to cultivation without any mulch results higher yield and higher yield quality, decreases need of irrigation and use of pesticides, and reduces leach of nutrients to water systems (Haapala et al. 2014). Paper, such as old newspaper and old packaging board, has been used for tens of years by home gardeners. Use of reel paper for mulching started in early 30´s. It remained limited and practically died down when low cost plastic mulches became available in late 50´s. Also use of plastic mulches remained low for decades until rapid growth started in 80´s (Jensen et al. 1995). According to Reynolds (2009) every year over 80 000 km^2 of agricultural land is covered with plastic mulch films.

From 2000 to 2007 annual world demand of plastic mulch films increased from 0.54 million tons to 1.4 million tons (Reynolds 2009). Most of the mulch films (70%) are used in Asia followed by Europe (13%) (Reynolds 2010). Polyethylene (PE) film is the dominating film type on the market. It is non-biodegradable and therefore it should be removed from the field after use. Mulch removal is mainly handwork and it is a cost for the farmer. Used PE-mulch is typically fouled by soil and crop residues and it can't be recycled. Use of mulch for energy generation is possible but in many cases mulch is disposed to a landfill. This is also a cost to the farmer. Plastic should be never mixed into soil, because plastic pieces stay in soil an unknown period of time. They can interfere with seed germination and root growth and small plastic pieces spread by wind are an environmental problem. Plastic should neither be burned at field site because the combustion process is uncontrolled and produces harmful gases to the atmosphere.

Availability of low cost biodegradable mulches which can be mixed into soil after the growing period would eliminate the problems of collecting and disposing of used mulch material. To be a viable alternative, biodegradable mulch film should perform comparably or at least satisfactory to polyethylene mulch film in crop production regarding easy mechanized laying, weather resistance, decay resistance and ability to prevent weed growth. Once the cropping season is over, the biodegradable mulch should degrade so that no accumulation occurs. The present biodegradable plastic mulches are 2 – 3 times more expensive (price per kg) than PE-mulch films making their use costly for farmers (Beaurepaire 2013, Querrini 2013).

MATERIALS and METHODS

This research was started by defining requirements for paper mulches suitable for annual and perennial agricultural crops. Only such papers and additives were accepted for testing which were safe from the environmental point of view. Screening of potential paper mulches was started in 2010 from 32 different paper qualities. Papers were characterized in the VTT laboratory in terms of their thickness, specific weight, opacity, tear and tensile strength, stretch and biodegradability. Preliminary laboratory tests were complemented with field tests. Paper pieces 0.16 m x 0.16 m in size were fixed randomly (4 of each paper quality) to a woven PVC-fabric. Three identical fabrics were made. One of them was placed on the soil surface and covered with a transparent roof 0.8 m above the soil surface. The idea was to get the paper in a contact with soil but to protect it from rain. Another fabric was placed on the soil surface under the bare sky laid open to rain. The third fabric was buried 2 – 4 cm under soil surface. The condition of the mulches and the state of decompostion was monitored weekly (those two trials on soil surface). Soil moisture and temperature 10 cm below the mulches were recorded with a data logger and results were compared with bare soil. The test was continued for 79 days and after it the condition of mulches and their decomposition rate was evaluated. Results of the laboratory tests and the field trials were used for selecting mulches for further tests and for improving their properties.

Table 1. Summary of the field trials 2010-2013.

Time	Place	Description
Summer 2010	Viikki, Finland	Screening of 32 candidate paper mulches
Spring 2011	Adana, Turkey	Screening of the most potential paper mulch candidates in Mediterranean conditions
Summer 2011	Viikki, Finland	Tests of mechanized laying, cucumber and maize field trials with different paper types and biodegradable plastic
Spring 2012	Adana, Turkey	Water melon field trials with different paper types
Summer 2012	Viikki, Finland	Tests of mechanized laying , cucumber and maize field trials, with different paper types and biodegradable plastic
Autumn 2012 and winter 2013	Mbebene, Swaziland	Butternut field trials with four different paper mulches.
Spring 2013	Adana, Turkey	Water melon field trials with different paper types in plastic tunnels
Summer 2013	Viikki, Finland	Tests of mechanized laying with a modified machine, earthing of mulch edges, cucumber and maize field trilas with different paper types and biodegradable plastic
	Piikkiö, Finland	Paper mulch in sugar beet growing
	Zaragoza, Spain	Paper laying tests and field tests with pepper

Suitability of paper mulches for mechanized laying was tested along with the laboratory and field tests. A standard plastic laying machine was used for testing. The aim was that the machine could be used both for paper and plastic film laying without any significant changes in the construction of the machine.

Paper mulches were tested also in field trials of different field crops. In Finland trials were made with cucumber, maize, and strawberry, in Turkey with water melon, in Spain with red pepper, and in Swaziland with butternut. Soil moisture and temperature was recorded with data loggers in the same way as in the screening trials earlier. Summary of all field trials is presented in the table 1.

The VTT laboratory and the participating companies developed new paper mulches during the project by changing paper chemical composition and by thermal and mechanical treatments. The aim was to develop paper mulch qualities suitable for field conditions in terms of acceptable biodegradability, good layability, and satisfactory ability to control weeds and soil moisture. Polyethylene film, commercial paper mulches, and well known biodegradable plastic films were used as reference material.

RESULTS and DISCUSSION

Development of mulch papers

Extensible papers (sack papers) made from soft wood chemical pulps, the basis weight being 70 g/m^2 or more, were stress resistant and they could be laid on a soil bed without severe difficulties by using a conventional plastic mulch laying machine. However, the paper edges, which were buried under soil, degraded too fast i.e. within a couple of weeks. In order to be usable for mulching the edges should stand decomposition so long that the plants grow on the mulch and prevent them from loosening. This will happen typically within a few weeks after seeding or planting. Without a weight on the mulch wind detaches it from soil.

Laying machines stretch the mulch on the bench and for this reason elasticity is important for all mulches. Mechanical laying of papers made from mechanical pulps or chemimechanical pulps (90 g/m2) was difficult or even impossible despite clupak or creping treatments which made the paper extensible. The material strength of those papers was too low for mechanical laying.

Paper extensibility was increased in machine direction (MD) by clupak or creping treatment from 1 - 2% to around 5 - 10% and in cross direction (CD) 20 - 40% respectively. 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 the orientation in paper´s MD-direction is the higher its extensibility in CD-direction is. CD extensibility can be also increased by allowing cross-directional shrinking of paper in paper machine’s drying section, but normally means to control CD shrinking are limited. The significance of CD extensibility to stress resistance of paper mulches remained unclear. It´s plausible, however, that extensibility in both machine and cross direction is beneficial for fluency of mechanical laying of the paper on soil. Elongation of paper mulch in mechanized laying helps also the paper to settle tightly on the soil.

Clupak- and creping treatments made mechanical laying of mulch papers manufactured from mechanical and chemimechanical pulps easier. However, field experiments showed that such papers tend to loose their tension (relaxation) on 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.

Table 2 presents approximate minimum tear and tensile strengths that extensible paper mulch should have if laid mechanically with a machine. The figures are based on experiences gained in the field experiments.

Table 2. 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

The mulching papers should have sufficient tear strenght in order to stand stress caused by laying. The most feasible way to improve the tear strength of paper mulches made from mechanical or chemimechanical pulps was addition of long poly lactic acid (PLA) or viscose fibres into the pulp mixture. Compared to other synthetic fibres the advantage of PLA and viscose fibres was their biodegradability in soil. Although PLA is often considered as biodegradable and compostable its decomposition in soil needs to be assured. Even at relatively low proportions, with their high fibre length (in performed tests 6 mm), the synthetic fibres contributed to a significant increase of the tear strength. With the highest tested proportion (20%) the increase of the tear index in PGW based stock was 243% with PLA and 177% with viscose fibre. The positive effect of the synthetic fibres on the tear strength was at least partially offset by the simultaneous decrease in the tensile strength and tensile stiffness. The stretch at break remained unchanged. Thickness reduction of the synthetic fibres resulted in an increase of the tear strength. The results of the experiments showed that synthetic fibres can be used to increase the tear strength of papers made with mechanical or chemimechanical pulps. The effect originated from the high fibre length producing mechanically well entangled network, coupled with the high strength of the synthetic fibres. The gained tear strength (index) was well comparable to the tear strength of softwood chemical pulps. The tTensile strength, unfortunately, remained at significantly lower level (Fig. 1 and 2). 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. Such an experimental arrangement could not be carried out in the present study.

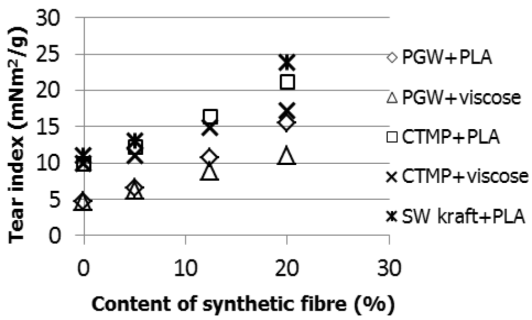

Figure 1. Tear index of the sheets made with a minor share of synthetic fibre. With PLA the tear index increased 117% in CTMP and 243% in PGW stock, while with the viscose fibre the index increased 77% and 141% respectively. In softwood kraft the tear index increased 118% (Asikainen & Korpela 2014)

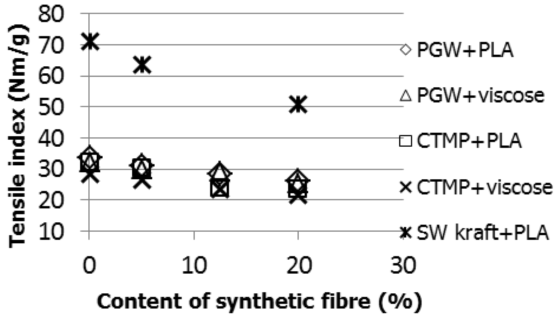

Figure 2. Tensile index of the sheets as a function of the synthetic fibre content. With PGW and CTMP the standard deviation ranged from 0.8 to 2.2 Nm g^{-1} and in SW kraft from 2.0 to 2.8 Nm g^{-1} (Asikainen & Korpela 2014)

Resistance against biodegradation in soil

The decay rate of the paper mulches in soil was ruled by lignin content of paper fibers. The lower the lignin content was the shorter the decay time was. The result is in accordance with earlier reported results (Vikman et al. 2002). Slow biodegradation of lignin is supposed to be due to its complex branched polymeric structure (Hubbe et al. 2010). Paper made from chemical pulp fibres (sulphite or kraf pulp fibers) contains 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) contained most of the native lignin of wood fibres (around 30 weight-%). Biodegradation of such papers took around 3 months or more, which is a long time enough in most cultivation conditions. The observed biodegradation rates were quite the same in greenhouse and in field tests. 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 soil and can resist stresses caused by wind and rain, but the edges of the paper mulch buried in the soil biodegraded much too fast. The severity of the problem depends on climatic conditions. In Spain, where the climate and topsoil are drier than in Finland (in average) the problem was not seen that pronounced (Cirujeda et al. 2012). Also, some of the cultivated plants like melons grow fast and they are capable to hold the paper on ground despite the decay of 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 were sulphate lignin (Indulin AT), acidic minerals, and formats. None of these chemicals did not significantly delay the biodegradation of paper mulches while thermo wood treatment improved biodegradation resistance of PGW, CTMP and corrugated boards. After one year burial in soil no biodegradation of the samples was observed.

Soil temperature and moisture

Black-coloured and wax-treated (transparent) paper mulches raised the soil temperature 0.2 – 2.6°C in the depth of 10 cm compared with bare soil. The temperature difference between mulch-covered soil and bare soil was the highest in the beginning of the growing season when the intensity of solar radiation was the highest and plant leaves did not shade the mulch or the soil surface.

Plastic mulches retained soil moisture better than non-coated paper mulches. In general, mulches prevented water evaporation and reduced need for irrigation.

Weed control

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 was one-side printing of the paper with a 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 happened with plastic mulches as well. Papers treated with wax and oil were more transparent for light than untreated allowing weeds to grow under the mulches and to lift the mulches up making them prone to wind damage. This problem was observed in Finland, Turkey and Spain. However, the amount of weeds under the waxed and oiled papers was less than in bare ground treatments.

Paper mulch impact on yield and yield quality

Yield results of cucumber (*Cucumis sativus*) trials in Finland are presented in the Figure 3 as relative values. Trials were made in 2011-2013. The average for biodegradable plastic was 200 and that for four paper mulches 176. The yield difference between plastic and paper mulches could result from plastic's better ability to prevent water evaporation in contrast to paper mulches.

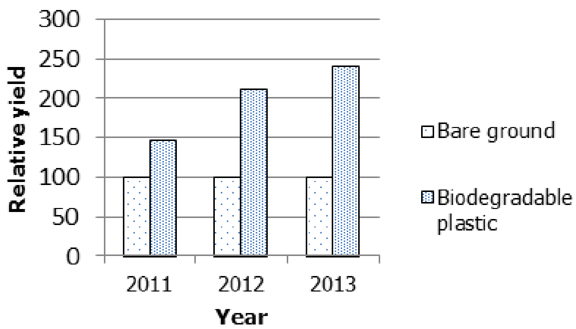

Figure 3. Relative cucumber (*Cucumis sativus*) yields of field trials 2011 - 2013 in Finland

In Turkey (2013) there was no difference between watermelon yields (*Citrullus lanatus var. lanatus*) grown on paper mulch and on bare ground. Melons were grown in plastic tunnels in the beginning of the season and perhaps for this reason mulch had no impact on the yield. However, the mulches prevented the growth of weeds and thus weeding was not needed in these plots making growing less laborious.

In Spain (2013) experimental paper mulches were tested with a commercial polyethylene mulch, with three different biodegradable plastic mulches, and with one commercial paper mulch. After two harvests the paper mulches had produced equally or more red peppers (*Capsicum annuum*) than polyethylene and biodegradable mulches.

Mulches help to maintain good fruit quality especially with plants which grow on the top of the surface e.g. cucumbers and melons as the fruits aren't in contact with soil.

Laying of paper mulch with a laying machine

Paper mulch stood mechanical laying on a soil bed without tearing if the tear strength was > 800 mN and tensile strength > 3 kN m^{-1}. Paper mulches with lower tear and tensile strengths could be laid on flat soil without noteworthy tearing, but when laid on a soil bed, they tore so badly that laying interrupted constantly and due to many tears mulch was vulnerable for further tearing caused by wind. Paper mulches with low tear and tensile strength were sensitive for tears caused by wind although they were undamaged after laying. Tearing started mostly from planting holes. Round planting holes would perhaps prevent wind tearing, but a more advanced tool than a simple edge would be needed for doing planting holes or they should be done in advance. Sometimes birds pecked holes into the mulch and these holes could also be starting points for wind tearing. An conclusion was made that the mulch must have a certain strength in order to stand the stress of mechanical laying and this strength is needed later on to prevent tears caused by wind.

CONCLUSIONS

Paper mulches made from mechanical or chemimechanical pulps were not always sufficiently stress resistant to stand stress caused by laying but resistance could be improved by clupak and creping treatments which made the paper mulches more extensible.

Paper mulches could be laid mechanically on a soil bed without paper tearing problems if their tear stength in machine and cross direction was >800 mN and tensile strength >3 kN/m respectively. Paper mulches with lower tensile strenght could be laid without significant problems on flat soil.

Paper mulches made from mechanical or chemimechanical pulps resisted biodegradation till the end of the cultivation season, while paper mulches made from chemical pulps degraded too fast. Especially their edges under soil degarded in two weeks. Degradation could not be prolonged by adding conventional paper making chemicals such as hydrofobizing agents and wet strength agents.

The best paper mulches performed comparably to conventional PE 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 main advantage of biodegradable paper mulches was that, they could be tilled into soil at the end of the growing season. They did not spoil soil quality or cause littering of rural environment. No laborious removal work or costly landfilling of waste mulch was needed.

The impact of paper mulches on the crop yield varied from field trial to another, from cultivated plant to another, and from geographical location to another. Paper mulch never decreased the yield but in the best case the yield was double compared with the yield of bare soil.

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