WINFRIED SCHÄFER JAANA VÄISÄNEN MARJO PIHALA

TECHNIQUE OF GREEN MULCH SPREADING

VIHERKATTEEN LEVITYSTEKNIIKKA

VAKOLAN TUTKIMUSSELOSTUS 79

MAA- JA ELINTARVIKETALOUDEN TUTKIMUSKESKUS

VIHTI 2001

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Agrifood Research Finland

Maatalousteknologian tutkimus (Vakola)

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Technique of green mulch spreading. Viherkatteen levitystekniikka

Julkaisun osat

Tiivistelmä

Luomuviljely lisääntyi Suomessa nopeasti 1990-luvulla luomuviljelyyn siirtymistä edistäneen tukipolitiikan vuoksi. Monille karjattomille tiloille aiheuttivat kuitenkin ongelmia typen niukkuus, viljan heikko laatu ja rikkaruohojen lisääntyminen. Koska viherkatetta käytetään yleisesti lannoitteena ja eroosion torjuntaan trooppisessa maataloudessa, viljelijät yrittivät selvittää, voitaisiinko keinolannoitteiden typpeä korvata orgaanisten lannoitteiden kuten viherkatteen avulla. Menetelmän hankaluutena on kuitenkin käsityövaltaisuus, koska viherkatteen levittämistä käsityönä ei kyetä korvaamaan sopivan tekniikan avulla.

Tämä tutkimusselostus käsittelee pääasiassa viherkatteen levitystekniikkaa. Vuosina 1994-1997 kehitettiin ja testattiin viherkatteen levityskoneen prototyyppi MTT Maatalousteknologian tutkimuksessa. Tämän ja kolmen muun levitystekniikan arviointi johti siihen lopputulokseen, ettei optimaalista menetelmää ole vieläkään löydetty. Millään tutkitulla tekniikalla ei ylletty käsityön laatuun. Prototyyppi kuitenkin mahdollisti laajempien kokeitten suorittamisen, joissa käytettiin eri viherkatekasveja ja/tai viherkatekasvien sekoituksia.

Kokeet tehtiin vuosina 1996-1999 eri viherkatekasvilla: ruis *Secale cereale*, puna-apila *Trifolium pratense*, sinimailanen *Medicago sativa*, timotei *Phleum pratense*, nurminata *Festuca pratensis*, ruokohelpi *Phalaris arundinaceae* ja eri sekoitukset niiden välillä. Viherkate levitettiin seuraaville kasveille: keräkaali *Brassica oleracea var. capitata*, takiainen *Arctium lappa*, virmajuuri *Valeriana*, piparminttu *Mentha piperita*, anisiisoppi *Agastache foeniculum*, nokkonen *Urtica dioica*, kevätvehnä *Triticum aestivum* ja kevätohra *Hordeum vulgare*.

Kokeiden perusteella päädyttiin seuraaviin johtopäätöksiin: 1) viherkatteen lannoitusvaikutus on epäselvää, 2) sääolosuhteet vaikuttavat sekä viherkatteen maatumiseen että viherkatteen runsauteen, levityksen ajoitukseen ja toistuvuuteen, 3) ruis tai ruokohelpi muodostaa kestävän katepeitteen, 4) nelinkertainen viherkatekasvin pinta-alan verrattuna viljelykasvin viljelypinta-alaan vaikuttaa riittävältä rikkaruohontorjuntaan, 5) viherkatteen levityskoneen prototyyppi toimii tyydyttävästi kaikilla käytetyillä viherkasveilla paitsi nuorella, märällä puna-apilalla.

Vuorotteleva kaistaviljely ja riviniittokone (Fischer Reihenmulcher) on tällä hetkellä paras saatavilla oleva viherkatteenlevitysteknologia suosiollisissa sääolosuhteissa. Vain "zero traffic" -teknologia mahdollistaa täydellisen viherkatteenlevityksen sää- ja maaolosuhteista riippumatta. Pohjois-Euroopan sääolosuhteista johtuen viherkatteen kasvu ja maatuminen on kuitenkin niin epävarmaa, että parannettu levitysteknologiakaan ei kykene luomaan viherkatteen käytölle riitäviä edellytyksiä. Sen sijaan trooppisilla alueilla korkea lämpötila ja kosteus takaavat sekä viherkasvien elinvoimaisen kasvun että nopean maatumisen.

Palkokasvien runsaus viljelykierrossa ja karjanlannan käyttö on joka tapauksessa viherkatetta suositeltavampi menetelmä lannoittaa luomuviljelyksiä Pohjois-Euroopassa. Toinen vaihtoehto on palkokasvien siemenrouheen, sarvijauheen tai risiinikakun käyttö. Näiden luonnonläheisten lannoitteiden käyttö ei riipu sääoloista ja ne voidaan tuottaa ja hankkia kaukana levityspaikalta.

Viherkatteen käyttö on maailmanlaajuisesti tärkeä menetelmä kestävän kehityksen periaatteita noudattavassa maataloudessa. Vaikka kate levitetään trooppisissa maissa vielä yleisesti käsin, kasvaa viherkatteen levityksen koneellistumisen merkitys lähitulevaisuudessa.

Avainsanat (asiasanat)
viherkate, levitystekniikka, luonnonmukainen viljely

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Abstract

Finland's policy of subsidising the conversion to organic production precipitated the rapid growth of organic farming in the 1990's. As a consequence, many stockless farms encountered the problems of nitrogen deficit, poor grain quality, and weed control. Since the spreading of green mulch on cash crops is very common especially in tropical agriculture, organic fertilisers like green mulch may be an alternative that would compensate for the prohibition on the use of mineral N-fertilisers. However, one problem is that presently there is no appropriate technique available to substitute for the strenuous handwork of spreading green mulch.

The main subject of this research report is the technique of green mulch spreading. Between 1994 and 1997, a green mulch spreading prototype was developed and tested. An evaluation of four different spreading techniques, including the prototype, revealed that the optimal technique was still not found and that none of the techniques considered in this report achieved the quality of hand work. The prototype did, however, allow us to perform experiments using different green mulch crops and/or mixtures of green mulch crops to a greater extent.

From 1996-1999 experiments were conducted using the following crops as green mulch: rye *Secale cereale,* red clover *Trifolium pratense,* alfalfa *Medicago sativa*, timothy *Phleum pratense*, meadow fescue *Festuca pratensis*, reed canary grass *Phalaris arundinaceae* and different mixtures of them. Green mulch was applied to following cash crops: Cabbage *Brassica oleracea var. capitata*, burdock *Arctium lappa*, valerian *Valeriana*, peppermint *Mentha piperita*, anise hyssop *Agastache foeniculum*, stinging nettle *Urtica dioica*, spring wheat *Triticum* aestivum, and spring barley *Hordeum vulgare*.

The experiments produced the following results: 1) The fertilising effect of green mulch application is ambiguous. 2) Weather conditions influence both the mineralisation and the quantity of green mulch, the timing, and the frequency of mulching. 3) Persisting green mulch cover can be achieved using rye or reed canary grass. 4) An area ratio of 4 : 1 green mulch crop : cash crop seems to be sufficient for weed control. 5) With the exception of wet young red clover, all of the green mulch crops used were suitable for the prototype machine.

On condition that the weather is suitable, the strip intercropping technique in combination with the row mulching machine of Fischer Ltd. is presently the best available green mulch spreading-technique. Only zero traffic technology such as gantry technology offers perfect green mulch spreading which is independent from weather and soil conditions. However, even improved spreading technique does not solve the other problem, which is caused by weather conditions: Uncertain growth and mineralisation of green mulch. This is mainly a problem in North European countries where conditions are the opposite of those in tropical areas. In tropical areas, temperature and humidity always ensure both, vigorous growth and rapid mineralisation.

In any event, a legume-rich crop rotation and organic manure from livestock would be the better alternative for fertilisation in organic farming under North European conditions. Another alternative is the use of milled seeds of legumes, hornmeal or cake of *Ricinus communis*. For these materials, traditional fertilising machinery is available. The application of these organic fertilisers is not weather dependent and they can be produced and purchased far from the location of application.

The worldwide application of green mulch is essential for a sustainable agriculture. Although in most tropical countries spreading is still done by hand, the mechanisation of green mulch spreading will gain increasing importance in the near future.

Key words
Green mulch, spreading technique, organic farming

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Finally, I would like to express my deep satisfaction that my negotiations with Walter Kress (Hardthausen/Germany) led to the construction of a row-mulching machine similar to the modified disc mower I had proposed as an alternative for the modified flail. A group of farmers, agricultural engineers and scientist were awarded with the third Karl Werner Kieffer-Prize 2001 for developing a row-mulching machine. This validated the best available technique theoretically forecasted in this study report.

Vihti, 21.12.2001

Winfried Schäfer

1 INTRODUCTION

Finland's policy of subsidising the conversion to organic production precipitated the rapid growth of organic farming in the nineties of the last century. As a consequence many stockless farms encountered the problems of nitrogen deficit, poor grain quality and weed control. Organic fertilisers like green mulch appeared to be an alternative that would not only compensate for the prohibition of the use of mineral N-fertilisers but also suppress weeds. Another advantage was, at least in the past, that fallow green land was allowed to be used as source of green mulch supply. Economically green mulch seemed to be suitable for intensive organic vegetable production like cabbage.

The spreading of green mulch on cash crops is very common especially in tropical agriculture where the main purpose is for nitrogen fertilisation and prevention of soil erosion. In addition, the application of green mulch has many advantages: Pest control, weed control, regulation of soil moisture, and nitrogen fertilisation. One problem is however, that there is no appropriate technique available yet to substitute for the strenuous handwork of spreading green mulch. Another problem lies in choosing the optimum combination of green mulch crop and cash crop, since timeliness of spreading, mineralisation characteristics, climatic factors and the C/N ratio of the green mulch crop or crop mixture influence nitrogen supply, nitrogen intake and nitrogen losses. The subject of this research report is mainly the technique of green mulch spreading.

2 STATE OF KNOWLEDGE ON GREEN MULCH RESEARCH

The most intensive research in green mulch application is dedicated to tropical agriculture, **figure 1** (CIIFAD/MOIST 1997). Many publications dealing with both green manure crops (peanut, bambarra ground nut, canavalia ensiformis, pigeon pea, chick pea, crotalaria, desmodium, dolichos, lablab, mucuna, cow pea) and cropping techniques (intercropping, alley cropping, multiple cropping, mixed gardens, conservation farming) demonstrate the great importance of green mulch spreading worldwide (e.g. DE SORNEY, 1916, SANCHEZ 1976, KARUNAIRAJAN, 1982, WILSON ET AL. 1986, FERNANDES ET AL. 1992).

Figure 1: Maize growing through velvetbean (*Mucuna spp*) mulch (Picture courtesy of Roland Bunch). Source: www.tropag-fieldtrip.cornell.edu/docthurston/ smokinhome.html

2.1 Green mulch crops

Green mulch crops are mainly legumes because of their high nitrogen content. Knowledge about suitable legumes for green mulch distribution in Europe is usual limited to fodder legumes. Compared with the large number of legume species, the number of cultivated legumes in Europe is very small. The legume database ILDIS presently (July 2001) contains more than 15463 species, 1573 subspecies, and 2329 varieties. The search term *Trifolium* meets more than 500 species (www.ildis.org).

The Department of Agricultural Sciences of the Imperial College at Wye administrates a database containing useful data about legumes. "The Organic Resource Database System (ORDS) ... has been designed as an effective means of collating much varied data on plant litter quality, decomposition, and animal feed digestibility and allowing complex relationship questions to be addressed" (GACHENGO et al. 1998).

Another source of information about suitable green mulch crops is the Genebank Information of The National Institute of Agrobiological Resources, Ministry of Agriculture, Forestry and Fisheries of Japan. This database contains also images of certain legumes. (http://www.gene.affrc.go.jp/plant/image/legume.html)

2.2 Green mulch effects

The search engine of www.inf.net/finelib/ found in 2001 in the CAB abstracts database approximately 681 publications containing the term "green manure" in the title of publications and approximately 2866 publications dealing with green manure in the past 30 years. The term "living mulch" was found 102 times, the term "plant litter" 1918 times. A literature review exceeds the scope of this report since most of the publications concern tropical agriculture. However, some selected publications representative of green mulch spreading-techniques under Northern European conditions will be mentioned here.

2.2.1 Mineralisation and fertilisation

The mineralisation of green mulch depends on temperature, humidity, and C/N ratio (FACELLI & PICKETT 1991). LARSSON & LINDÉN (in LARSSON 1997) observed, that mineral N from green mulches is not exceeding 16 % of applied N. "Some mineral N in soil originating from mulches could be recovered already 14 days after mulching, reaching maximum accumulated amounts 55-70 days after mulching". PROCHNOW ET AL. (2000) found that the duration of meadow mulch mineralisation increases with mulch yield and delay of cutting time. Meadow mulch mass mineralisation may be calculated with the formula

$$m_t = m_0 - 10^{-4} m_0 (10.1 p + 6.34 T) \qquad \text{for the first cut}$$

and

$$m_t = m_0 - 10^{-4} m_0 (40.3 p + 5.21 T) \qquad \text{for the second cut}$$

where

m_t	g m^{-2}	dry matter of mulch at time t
m_0	g m^{-2}	dry matter of mulch at cutting time
p	mm	sum of precipitation between cutting time and time t
T	°C	sum of daily mean temperature between cutting time and time t

According to these results, mineralisation in terms of mass reduction is very slow, e.g. with $m_0 = 300$ g m^{-2} 50% of cut meadow mulch mineralises within 50 days after the first cut and within 40 days after the second cut. Further PROCHNOW & KLEINKE (1995) report, that mineralisation in terms of mass reduction and N-supply is not significantly dependent on chopping technique or chopping length. N-content of mowed or chopped green mulch was still 66-87% four weeks after chopping and 33-49% eight weeks after chopping compared with N-content at cutting time.

SCHÄFER ET AL. (1995) reported, that 2.5 - 3.1 kg m^{-2} dry matter red clover green mulch supplied enough nitrogen to raise significantly the yield of cabbage, **figure 2**.

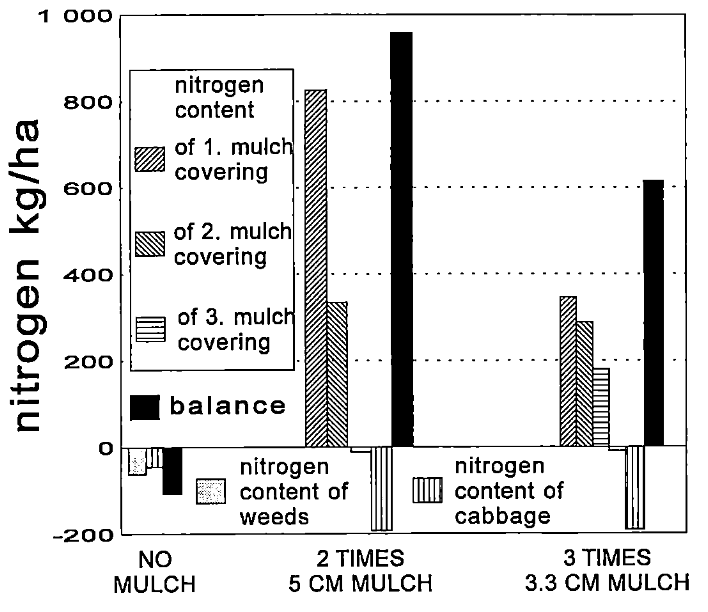


Figure 2: Nitrogen balance of red clover green mulch on cabbage. (SCHÄFER ET AL. 1995)

2.2.2. Weed control

Green mulch cover suppresses weed growth, **figure 3**. However, for effective suppression of weeds high volume mass of green mulch is necessary. JAAKKOLA (1995b) reports, that three times a 3 cm layer (220 t ha^{-1}) of chopped *Trifolium pratense* is necessary to suppress weeds. LARSSON (1995) achieved with a 5-10 cm layer (30 t ha^{-1}) of green mulch 32% weed reduction. VISELGA ET AL. (1999) reports 9 % weed reduction using green mulch in potato growing.

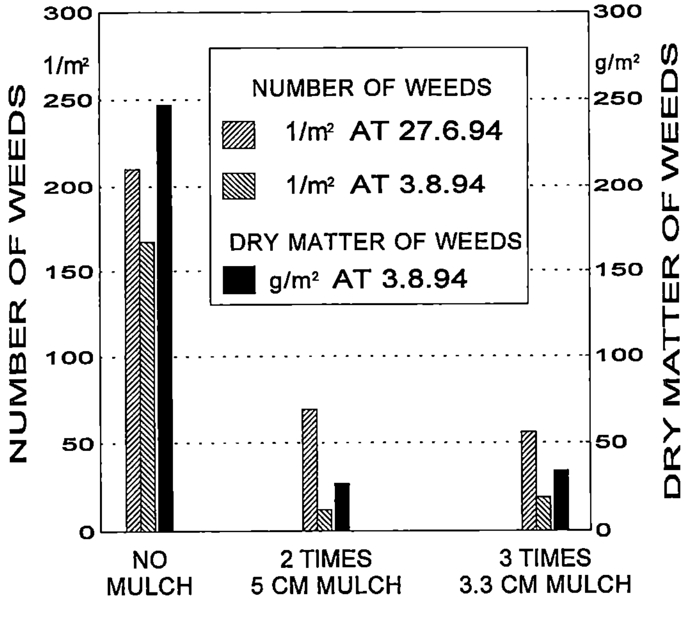


Figure 3: Number and dry matter of weeds depending on frequency of green mulch application (SCHÄFER ET AL. 1995)

2.2.3 Pest control

HELLQVIST (1996) studied the influence of grass mulch on pest in cauliflower. He reports that mulching with grass clippings increased yield and reduced damage by root maggots. Mulching did not reduce brassica root fly *Delia floralis* pupae per plant but decreased the rate of parasitisation by *Aleochara bilineata*, resulting in a higher number of healthy pupae per plant.

2.2.4 Soil temperature and soil moisture

SCHÄFER ET AL. (1995) reported the positive effect of green mulch on soil humidity, **figure 4**. LARSSON (1997) who observed "evaporation is strongly reduced by organic mulching" confirms the findings. Further she reports "organic mulches acted as insulating coverings, reducing diurnal temperature variations and keeping soil temperature cooler than bare soil during spring and summer".

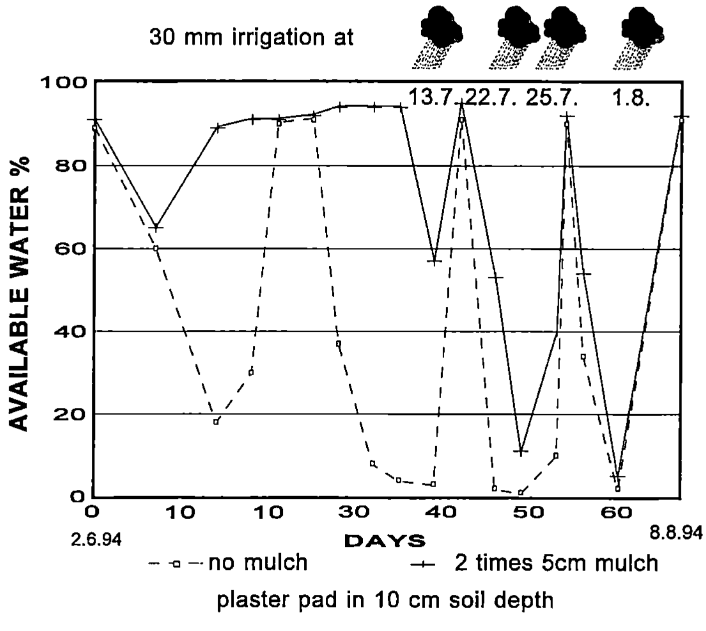


Figure 4: Effect of green mulch upon soil moisture

2.2.5 Soil fertility and N-losses

LARSSON (1997) measured carbon and nitrogen release from decomposing green mulches. She found, that "recoveries of N from the mulches as mineral N in soil were low, not exceeding 16% of applied N, indicating that the fertilizer efficiency of applied N is low from green mulches".

Nitrogen losses from green mulch reported for example by WHITEHEAD ET AL. (1988), GLASENER & PALM (1995), and LARSSON (1997). PROCHNOW & KLEINKE (1995) assume that N-emissions of green mulch in terms of NH_3, NH_4, or N_2O are inconsiderable and do not exceed the common level of green land. There are no negative effects on the environment. LARSSON (1997) estimated the NH_3-N loss equivalent of 17 % of the applied N for alfalfa to 39 % for high N grass. N_2O-N losses are estimated to be 1 % of applied N.

3 STATE OF GREEN MULCH TECHNOLOGY

The need for mulching machines has occupied agricultural engineers already since the 1950's (HURLBUT 1950, HARROLD, L.L. & DREIBELBIS, F.R. 1950). The main problem was to find methods and machines that would impede soil erosion in the United States (CHEPIL et al. 1960). There was the development of a furrow-mulch ridger in the 1970's by RICHEY & GRIFFITH (1977). "The concept was to make ridges with the residue of the previous crop left on the surface but in furrows between ridges". For this purpose, different prototypes were developed and finally a modified drawn flail shredder did the job. Another concept to protect tree seedlings with mulch made from logging residues was developed by KOCH & MCKENZIE (1977). HYDE ET AL. (1986) who developed a slot mulch implement for installing straw-filled slots for the purpose of erosion control. Efforts to develop mulch machines for erosion control finally resulted in no-till techniques. Presently all big agricultural machinery manufacturers offer direct seed drills.

3.1 Machines for grassland

For mulching fallow plots, roadsides, and pastures, fodder harvesting machines like mowers and flail is suitable. Special mulching machines for tending green fallow was developed in the 1990's, after the EU started to pay subsidies for the conversion of arable land to green fallow. Meanwhile there is a wide range of special machines on the European market available, but in Finland, the number of models to choose from is very limited.

Beside flat flail tools, nowadays Y-shaped tools or a combination of both tools are in common use. Mulching implements are mounted on the back of the tractor (**figure 5**) or better at the front of the tractor (**figure 6**) to avoid wheel traces on unmowed mulch. Wide implements may be equipped with more than two supporting wheels to impede soil compaction. Mulching machines equipped with mower knifes (**figure 7** and **figure 8**) tend to swath formation of chopped mulch. A toothed screw was developed in the 1990's as mulching tool, reducing the danger of throwing foreign matter, **figure 9, figure 10**.

Figure 5: Back mounted flail mulching machine with four supporting wheels (dlz 4/1996, p.79)

Figure 6: Front mounted flail mulching machine (HASS 1996)

Figure 7: Rotary mulching machine (dlz, 2/1997, p.80)

Figure 8: Cutter-assembly of rotary mulching machine (dlz, 2/1997, p.80)

Figure 9: Saftey mulcher (Maschinenfabrik Bermatingen GmbH&Co., Germany)

Figure 10: Toothed screw-mulching tool (Maschinenfabrik Bermatingen GmbH&Co., Germany)

Further mulching machines for roadside mulching (**figure 11**) and tending meadows like golf courts, football fields, and other landscape areas is well developed. Modern design uses solar energy (**figure 12**) and laser technology for mulching (**figure 13**).

Figure 11: Roadside mulcher (Gerhard Düker KG, Germany)

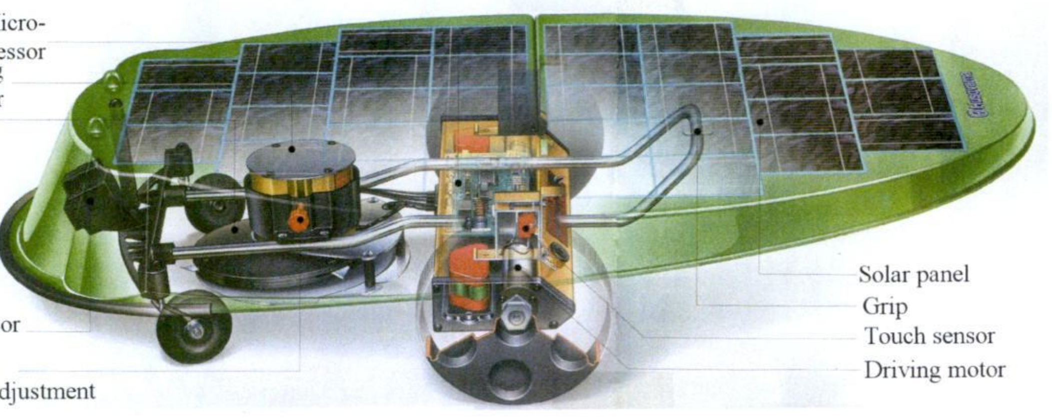


Figure 12: Solar mower (Husqvarna, Finland)

Figure 13: Laser mower (Der Spiegel, Nr. 43/2000, p. 236)

3.2 Machines for berries and fruit trees

Special mulching machines are available for berries and fruit-trees. They use the same cutting technique as mulching machines for meadows. **Figure 14** shows a mulching machine developed for strawberry cultivation. For bushes and trees, the cutting devices are usually mounted on a swivel arm equipped with stem sensors for steering the cutting device within the row **figure 15**. The cutting device may be replaced by rotary tillage tools, which mix the green mulch into the soil **figure 16**. IRLA & HEUSSER (1999) compared different implements and found that they work satisfactorily at working speeds of 3-5 km h^{-1}. For wet mulch, a completely different mulching technique is presented by ÖKOTERRA (1995). A mixture of organic agricultural residues, wood fibres, and water is distributed by two-row band spreading along the crop rows with a dribble hose attachment, **figure 17**. LINDNER (1996) reports, that the wet mulch is also suitable in lettuce glasshouse production.

Figure 14: Mulching machine in strawberry cultivation (Huko Ky, Finland)

Figure 15: Sensor operated swivel arm mulcher (Maschinenfabrik Bermatingen GmbH, Germany)

Figure 16: The Ladurner row mulcher works on the right side of the tractor operator (Ladurner Karl J. & Co.-OHG, Italy)

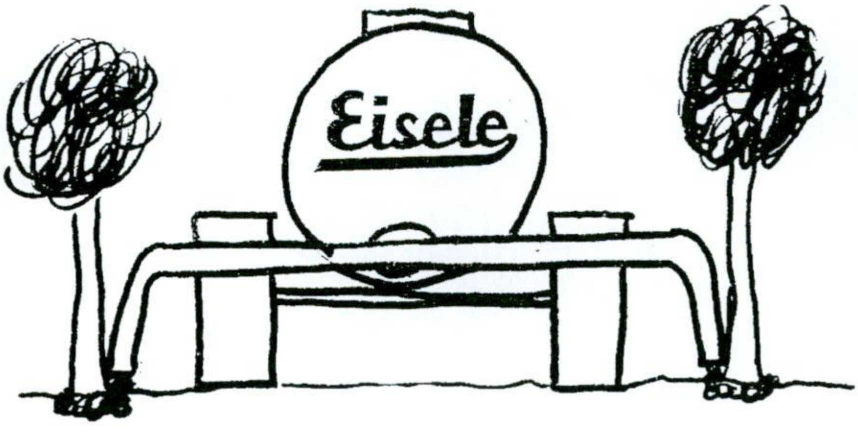


Figure 17: Wet mulch distribution (Ökoterra, Rentweinsdorf and Franz Eisele & Söhne GmbH & Co. KG. Sigmaringen, Germany)

3.3 Machines for cereals

In the beginning of the 1990's, some farmers tried to increase the quality of organically produced cereals by sowing cereals in wide row spacing and cultivating clover grass mixtures within the row spacing. The clover strips are used as green mulch for nitrogen support and weed control. The method was reported as successful by ALVERMANN (1997) and became the subject of research (SCHULZ-MARQUARDT, J. et.al. 1995, WEBER et.al. 1995, M.GERMEIER 1999). Efforts of farmers, researchers and manufacturers resulted in a row-mulching machine developed by Kress Ltd. and Fischer Ltd., **figure 18.** The new technique received the third Karl Werner Kieffer-award 2000 (ANONYM, 2001).


Figure 18: Row-mulching machine (Helmut Fischer Ltd., Gemmrigheim, Germany)

3.4 Machines for maize

In maize cultivation, mulch application is often a precondition of impeding soil erosion. Usually direct seed drill is used. Machines for strip cultivation are available as well as direct seeding machines (ANONYM 1995, ANONYM 1996). **Figure 19** shows a machine for maize cultivation combining direct seed drill and rotary tiller. **Figure 20** shows strip rotary tiller combined with chisel plough, fertiliser-, strip sprayer-, direct seeding-, and roller unit.

Figure 19: Strip rotary tiller with direct seed device. (Althaus Co. AG, Ersingen, Swiss)

Figure 20: Multipurpose strip rotary and direct seed machine (ANONYM 1993)

An economical assessment of different technical solutions of mulch seed systems is done by BRUNOTTE ET AL. 1996. The benefit of using direct seed machines after a catch crop is 0.5-5 fold higher than the additional costs for equipment and operation.

3.5 Machines for potato

Green mulch application for potato cultivation is the subject of intensive research at the Eidgenössische Forschungsanstalt für Agrarwirtschaft und Landtechnik (FAT) in Tänikon/Switzerland (SPIESS ET AL. 1997, SPIESS ET AL. 1999). Mustard and turnip rape was used as green mulch. To complete the whole machine chain of green mulch application for different mulching systems some prototypes were developed at FAT.

In Lithuania, green mulch application in potato cultivation was done using a centre pivot gantry. Because of chopped green mulch incorporated into the soil, soil compaction was reduced significantly at a depth of 9-18 cm. This enables potato-digging machines to be used more effectively. Energy consumption is also reduced. "Straight radial fingers with triangular cutting plates attached to the ends were optimal for mulching green manure crops" (VISELGA ET AL. 1999).

4 DESIGN OF A PROTOTYPE MACHINE FOR GREEN MULCH SPREADING IN ROW CROPS

4.1 Knowledge base when starting 1994

Currently, there is no appropriate technique available to substitute the strenuous handwork of spreading green mulch in row crops. In 1994 at the Agricultural Engineering Research Unit of MTT Agrifood Research Finland, a project was launched to develop a prototype for green mulch spreading in row crops. This project was part of the program of "Developing technology of ecological agriculture" in close co-operation with the Ecological Production Unit in Partala and the Plant Protection Unit in Jokioinen.

Results of preliminary trials gained by Sirkka Jaakkola, Heikki Talvitie, Antti Kallio and Kari Karusalmi were compiled: Trials of spreading green mulch were mainly done using cabbage as row crop and red clover as green mulch crop. Cabbage and clover were cultivated on different plots. Therefore, clover had first to be chopped and then to be transported to the cabbage plot. The first spreading of green mulch was done by hand 1-2 weeks after planting. A layer, 5 cm in height, corresponding to a wet green mass of 10 kg m^{-2} was considered sufficient. Spreading has to be done a second time three weeks later using 7-14 kg m^{-2}. The time limit for the second spreading is just before the cabbage fly starts flying.

The advantages of using green mulch are obvious: weed control, regulation of soil temperature, fertilising effects, pest control, and regulation of soil moisture. All these factors ensure high yield and good quality.

On the other hand there are problems too: the spreading by hand is very tedious and not applicable on larger areas. The precision of distribution is insufficient using a manure spreader, the optimum ratio of the culture:green mulch area varies in a wide range, chopped green mulch has to be spread immediately to prevent heating and getting mouldy, and fibres and parts of the mulching material should be chopped as short and fine as possible

The proposal to modify a common manure spreader for green mulch spreading was assessed critically. Although a prototype in Sweden already exists the following disadvantages were considered problematic: The heavy weight of the fully loaded trailer damages soil structure, long transport distances may cause heating of the green mulch material. Arranging the tractor-trailer system within row crops is difficult and requires at least 10 m headlands. Row crops get covered by green mulch too which would need to cleaned off by hand. In addition, because of the high quantities of green mulch required the trailer may have to be refilled before the end of the row is reached.

Based on these experiences the discussion about a suitable green mulch spreading-machine led to the following: The separate growing of row crop and green mulch crop on different plots must be replaced by a strip intercropping technique. The width of the strips depends on the tractors track width and the available tillage implements.

4.2 Design and testing

The decision was made to design and manufacture the prototype in Agricultural Engineering Research Unit's workshop according to the proposals of the farmer Mr. Antti Kallio. Mr. Kallio assisted Agricultural Engineering Research Unit's workshop staff during the construction period. The prototype was tested at Agricultural Engineering Research Unit's farm. Further research was planned in Peipohja, Partala and Jokoinen to find out suitable crop rotation systems concerning both, the green mulch strip and the culture strip as well as the timing of mulching depending on the cultivated crop and the mass of green mulch required. The first prototype was designed to meet the following terms of reference:

- Modification of an existing flail
- Area ratio green mulch crop : row crop 2:1
- 50 cm row distance between cabbage rows
- Strip width of clover according to working width of sowing machine: 2.5 - 3 m
- Three spreading heads
- Spreading head powered by a hydraulic motor

Based on these terms of reference a used flail was procured. The working width of the flail found was 1.2 m. A trial plot of about 60 m length was prepared for planting cabbage within 6 rows of 50 to 60 cm row distance. The planting was done on 18th of May 1994. During the following night all the seedlings froze but later recovered. On one side of the trial plot was a red clover strip, sown in the previous year and on the other side there was *Phacelia* and *Vicia,* which was sown in the middle of June.

Work on the flail began in the middle of May, when Jarmo Välläri joined the staff of the workshop. First, data on the dimensions of the machine was collected for making the drawings by means of a CAD-program. The first modification of the flail concerned the gear train. The original implement was guided beside the tractor which itself was pulling a trailer. Only the gearbox was mounted on the three-point linkage of the tractor. Then the whole implement had to be mounted on to the three-point linkage. This was achieved by fixing the gearbox in front of the flail by means of mild steel square bars and bolts. The V-belt pulleys then had to be mounted on the other side of the flail to ensure that the flail would turn in the original direction. The bearing brace, the V-belt protection cover and V-belt tension adjustment mechanism had to be moved accordingly. **Figure 21** shows the technical drawing of the modifications.

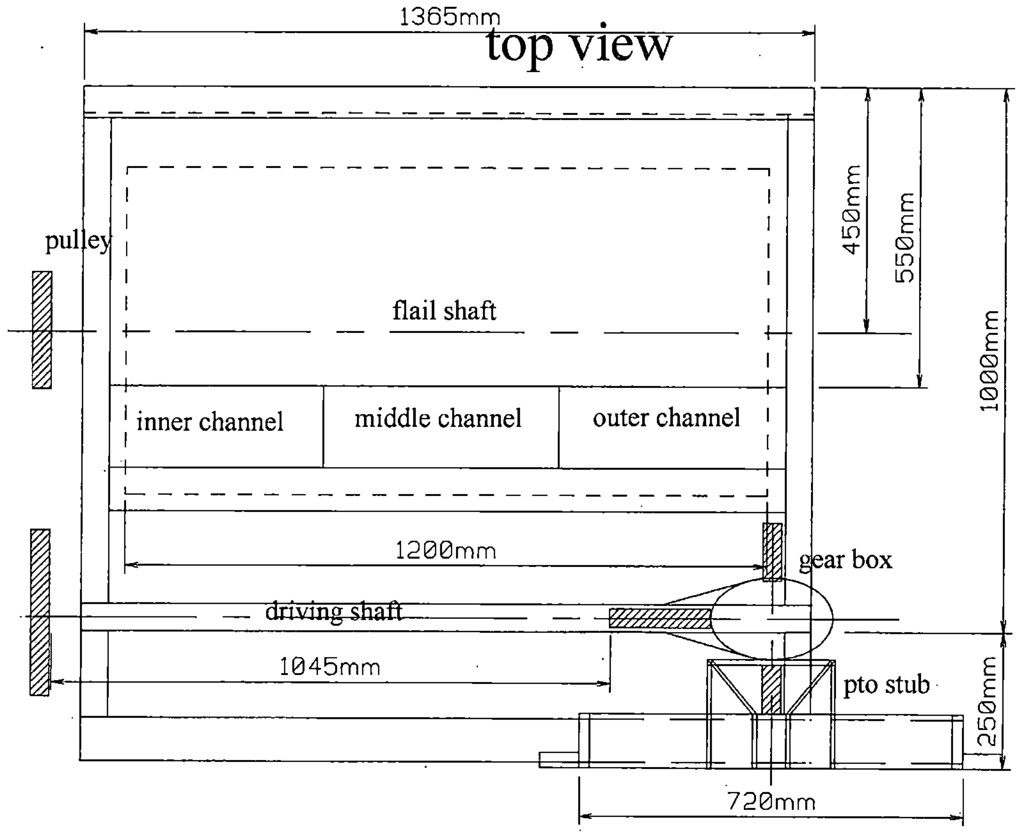


Figure 21: Flail for green mulch spreading after modification

After the modification of the gear train, the machine was tested. No problems occurred during the tests. Then the flail hopper had to be replaced by galvanised pipes 25 cm in diameter. To achieve this, the outlet slit of the flail was divided into three 40 cm wide segments. A short hopper to connect a pipe was provided for each segment respectively. First the shortest pipe, made of two 90° bendings, was mounted to the innermost segment hopper and the transfer of the green mulch sidewards through this pipe was tested. This test was successful. After this, the longest pipe, made of a horizontal pipe and two 90° bendings, was mounted to the furthermost segment hopper. This time the tests revealed that the horizontal pipe clogs up and therefore the pipe design was rejected.

Based on the experiences collected during the tests it was decided to use half-circular channels made of metal sheet. The front casing sheet of the flail was bent perpendicular to ensure that the green mulch did not suffer any friction before entering the channels. According to the width of the flail, the radius of the outer channel would be 1.2 m. However, the standard size of metal sheet is 1 x 2 m. To save work and to avoid welding joints in the channels, an ellipse shaped channel system was used instead of a circular shape. By this, the height of the channel was 1 m at maximum. At the vertex, the channel was divided into two halves joint by hinges. Each half was made of two standard metal sheets. Two ensure constant velocity of the air stream within the channels, the area of each channel was reduced continuously from 40 x 20 cm to 20 x 20 cm, **figure 22**. After completion of these modifications, the implement was tested on the field. Then the flow of chopped green mass functioned satisfactorily. Clover, Phacelia, and Vicia, were transported without problems under wet and dry conditions. Long grass however or tractor speed more than 4 km h^{-1} caused clogging in the uppermost channel. For green mulch application on row crops like herbs, a two-channel system was manufactured and used.

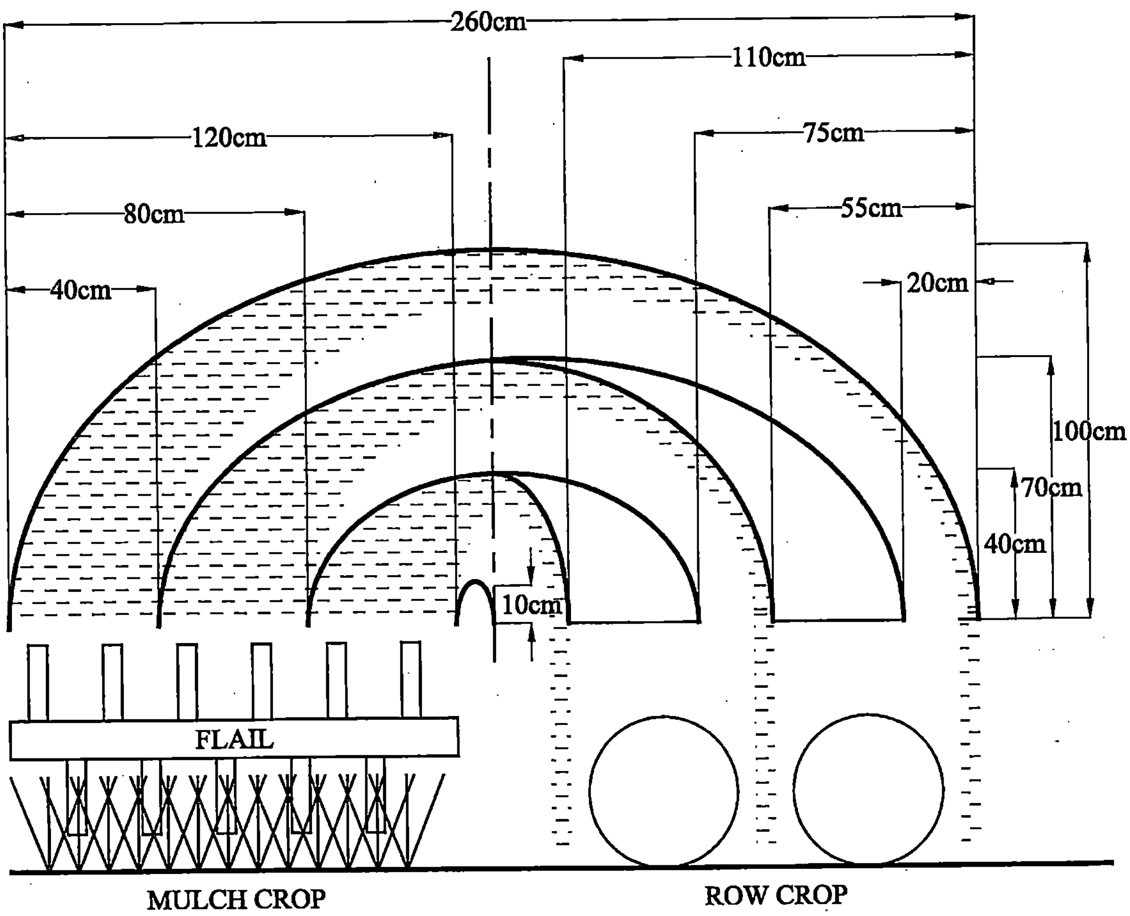


Figure 22: Final design of the channels

Next the spreading heads were designed. Mr. Anttila's original idea of was, to direct the chopped green mulch through the pipe into a hopper mounted on to the spreading head. The spreading head should spread the green mulch by a hydraulic powered grass mower. The hydraulic motor was first placed eccentrically into the hopper. The width of the mower blade was 40 cm to cut all weeds between the cabbage rows. The mower was guided by a parallelogram and supported by runners. Tests revealed, that the mower worked very well but the hopper clogged up immediately. Clogging could be avoided by lifting the hopper about 20 cm above ground, but then the green mulch was spread very widely and covered the top of the cabbage.

The design was now modified by placing the hydraulic motor outside the pipe and by using a metal wire instead of the mowing blade. The wire was supposed to avoid doing damage when hitting an obstacle and reduce the power required by the hydraulic motors. However, the wire did not work as expected because it touched the ground when the hydraulic motors started to work and was not then stretched by centrifugal forces. The mower blade replaced the wire again. After some further modifications, the final spreading head design worked satisfactorily. It soon became clear that the mowers are useless since three weeks after planting there are no weeds yet. Guiding sheets at each end of the channels proved very useful in guiding the flow of chopped material very close to the cabbage row. By ricocheting off the ground, the green mulch spreads itself within the row. The final design of the spreading heads and the guiding sheets is described in SCHÄFER ET AL. 1995. **Figure 23** shows the complete machine.

Figure 23: Prototype of the green mulch spreading-machine of Agricultural Engineering Research Unit

4.3 Conclusions

The prototype machine was used in subsequent years but unresolved problems and obstacles remain:

- The optimum spreading head has not yet been found or may be unnecessary.
- The implement should be mounted on the front of the tractor to avoid the tyres pressing down on the mulch to be chopped.
- The exact guidance of the machine needs an experienced operator due to problems with sight line obstructions.
- Wet red clover easily gets stuck in the channels
- The sowing machine for green mulch, the planting machine for cabbage and the green mulch spreading-machine must match each other in respect of strip width and working width.
- he transportation of chopped green mulch via the channel system is time and energy consuming because of low travel speed and high volume mass transport.

These constraints lead to the consideration, that it would be more efficient to shift the chopped green mulch straight sideways instead of conveying it through a channel system. This is easily achieved with conventional mowing techniques, e.g. drum, or disc mowers, see also chapter 5.1.4. Additionally the length of cut green mulch can be optimised. The following considerations may illuminate the idea:

Two disc mowers are mounted on front of the tractor to ensure that tractor tyres tread only on mowed green mulch strip. At each disc-mower, two blades are mounted. Because farmers - especially vegetable farmers in Finland - rarely own tractors with front-pto, powering of the mower prototype is done by electric motors. This also offers cheap and easy control of operating parameters like speed of rotation. A 16 kW pto-driven generator mounted on the 3-point hitch of the tractor supplies electric power. The prototype of the mower uses the following construction parameters:

r	cutting radius (disc including blade)
ν	rotation speed of the disc
β	angle of inclination of the disc (i.e. angle between plane of rotation and ground)
h	the mean cutting height (i.e. distance between the horizontal centre axis of the disc to ground)
v	forward speed of the tractor
n	number of blades per disc
e	effective cutting width of the blade

The mower radius depends on the area ratio between row crop and green mulch crop area and must therefore be adjustable. Further, it depends on the length of the blade mounted on the outer edge of the disc. Usually blades have an effective cutting width of 10 cm so that the disc radius is to be reduced by this amount.

The rotation speed depends on the green mulch crop properties and the forward speed of the tractor. Mowers usually use rotation speed greater than 2000 min^{-1} on 50 cm diameters which is corresponding to a circumference speed of $>52\ m\ s^{-1}$ to ensure cutting by impact. The travel distance of the tractor within the period of one disc revolution must be less than the effective cutting width of the blade to ensure that the blade hits all green mulch crops in the direction of travel.

With $v = s * t^{-1}$, $t = \nu^{-1}$ and $s < e$ this condition leads to the following equation:

$$v < e * n * \nu$$

Using standard values e = 10 cm, $\nu > 2000\ min^{-1}$ and n = 2 we get the maximum allowed tractor forward speed of $v < 24\ km\ h^{-1}$.

The angle of inclination of the disc β should be adjustable. The inclination in driving direction is upwards. Than the disc cuts the green mulch two times, **figure 24**. The cutting height h is defined as half of the average growing height of the green mulch plant.

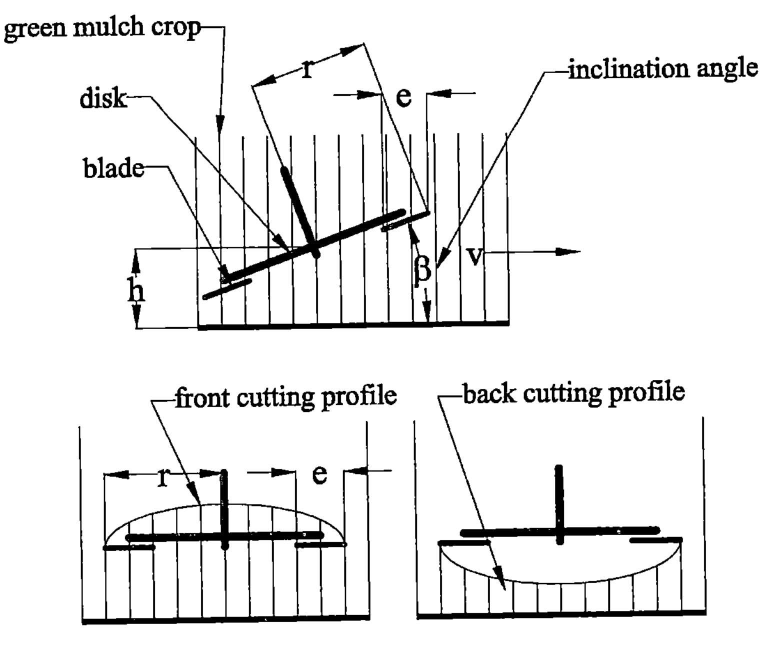


Figure 24: Cutting ellipse of an inclined disc mower. Side view upper, front view lower.

The optimum inclination angle β can be determined, **figure 25**. The vertical area A_m of the green mulch stock is

$$A_m = r * 4 * h$$

when the cutting height h is half of the green mulch crop height. The effective vertical area of the mower disc depends on the inclination angel β and equals the area A_e of the ellipse made by the vertical projection of the disc:

$$A_e = \pi * r^2 * \sin\beta$$

The upper edge of the mower disc cuts the green mulch first above the inclination axle, which divides the ellipse into two equal halves. So the upper half cut area is

$$A_{upper} = ½ * (A_m - A_e).$$

The cutting length l_{upper} ranges from the minimum in the middle of the disc $l_{upper} = h * (1 - \sin\beta)$ to the maximum at the outer edge of the disc $l_{upper} = h$ and is approximately determined by

$$l_{upper} \approx A_{upper} * (2 * r)^{-1}.$$

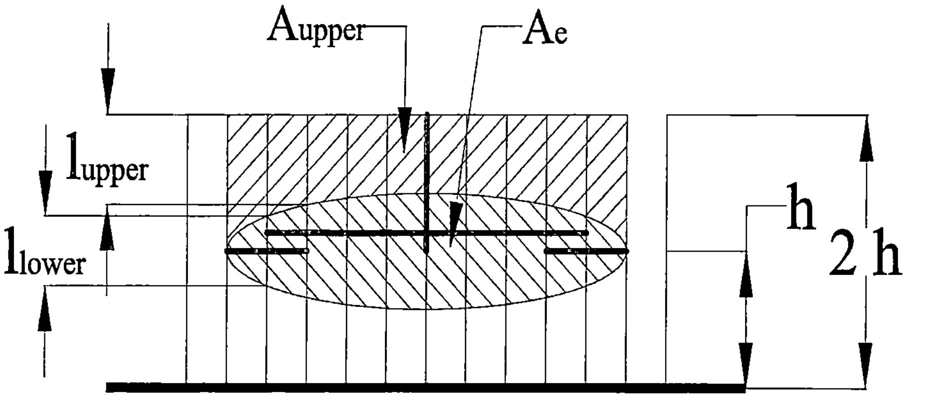


Figure 25: Distribution of cutting length of an inclined disc mower

The cutting length l_{lower} ranges from the minimum at the outer edge of the disc $l_{lower} = 0$ to the maximum in the middle of the disc $l_{lower} = h$ and is approximately determined by

$$l_{lower} \approx A_e * (2 * r)^{-1}$$

The condition for optimal equal cutting distribution is

$$l_{upper} = l_{lower}$$

or

$$A_e = A_m * 3^{-1}$$

By inserting the equations of the areas the optimal inclination angle β is calculated with

$$\beta = \text{arcsine}(4 * h * \pi^{-1} * r^{-1} * 3^{-1}).$$

Using a mower disc radius of 25 cm and a mean cutting height of 15 cm we receive an optimal inclination angle of β = 14.75° and a mean cutting length of 10 cm.

The evaluation of the prototype in terms of field efficiency, cost, and working quality in comparison with alternative techniques is subject of the following chapter.

5 EVALUATION OF GREEN MULCH SPREADING-TECHNIQUES IN ROW CROPS

The results of the evaluation of the following green mulch spreading-techniques were obtained by model calculations and partly by field experiments.

5.1 Techniques of green mulch spreading

The following green mulch spreading-machines are the subject of evaluation: the modified manure spreader used in Sweden for different experiments in past years; the green mulch spreading-machine described in chapter 4.2; the modified disc mower described in chapter 4.3, although there were no funds available to realise and test it in praxis.

5.1.1 Technique A: Modified manure spreader

This technique is used, when green mulch crop and row crop are cultivated on different plots. Green mulch is harvested by flail and transported to the row crop plot. A modified manure spreader as shown in **figure 26** distributes chopped green mulch. This technique was the subject of different experiments at the University of Alnarp (SVENSSON 1996) and elsewhere (HELLBE 1989).

Figure 26: Technique A, modified manure spreader (Luomulehti 7/97)

5.1.2 Technique B: Modified flail

The strip-intercropping technique of green mulch crop and row crop can reduce the transport of green mulch. By this technique green mulch may immediately be transferred from the green mulch crop strip to the adjacent row crop strip. Based on an idea of a Finnish farmer a prototype machine was developed from a modified flail (see chapter 4). Enlarging the area ratio between green mulch crop strip and row crop strip is the only way to increase the availability of green mulch. The increment of the green mulch crop strip width is linked to the working width of the flail. Therefore, the area ratio can only be enlarged stepwise. The step width is equal to the working width of the flail. **Figure 27a** shows the proceeding on an area ratio of 2:1. If an area ratio of 4:1 or greater is necessary, the green mulch must be chopped several times, **figure 27b**.

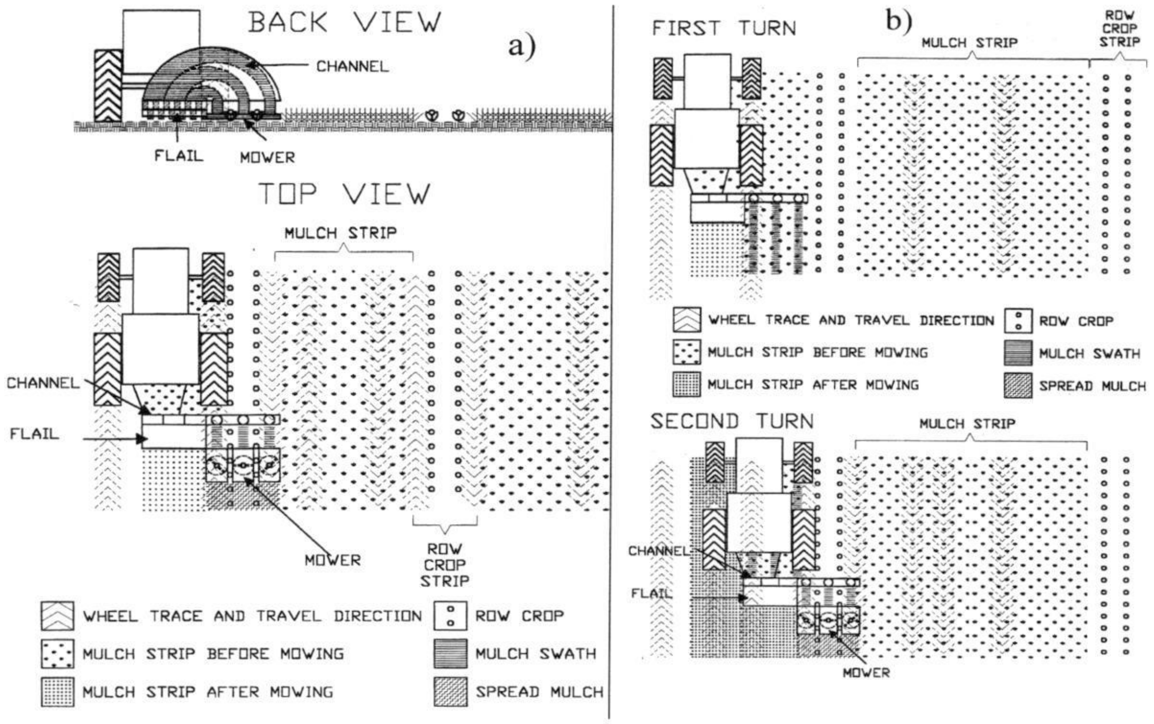


Figure 27: Technique B, modified flail. a) area ratio green mulch crop : row crop 2 : 1. b) area ratio green mulch crop : row crop 4 : 1

5.1.3 Technique C: Combination of modified manure spreader and modified flail

Another possibility is the combination of technique A and technique B especially if the quantity of green mulch and/or the timing of spreading green mulch using technique B causes problems. Additional green mulch can be collected for example from a fallow plot and discharged on the green mulch crop strip for further spreading as it is shown in **figure 28**.

5.1.4 Technique D: Modified disc mower

Based on the experiences using technique B another technique is proposed: within the green mulch crop plot single rows are prepared by a strip rotary tiller. Green mulch distribution may be realised using a modified drum or disc mower as shown in **figure 29**. This solution was realised in green mulch application in wide row spacing cereal production described in chapter 3.3 (GERMEIER 1999).

5.2 Evaluation methods

The evaluation of these four techniques and additionally the spreading by hand (technique H) was made by three different methods: Calculation of working time and field efficiency, rating of process specific criteria and calculation of costs. All calculations were made assuming the following conditions: The green mulch crop area is 4 ha or 2 ha and the row crop area is 1 ha. For technique A green mulch crop and row crop are cultivated on different plots. The distance between these plots is 1 km. The width of the row crop strip is 1.2 m for technique B and C and 0.3 m for technique D respectively. For technique C half the area of the green mulch crop is cultivated in strips alternating with the row crop. The other half of green mulch is collected from a green mulch crop plot 1 km away. Seedbed preparation for the row crop is performed by a rotary tiller. Two times 14 kg m^{-2} fresh green mulch is spread during the growing period. This requires a fresh green mulch yield of 70 t ha^{-1} during the spreading period or 35 t per ha and cut. Travel speed for transport is 5 km h^{-1} and the manure spreader's capacity is 3.9 t or 13 m^3 respectively.

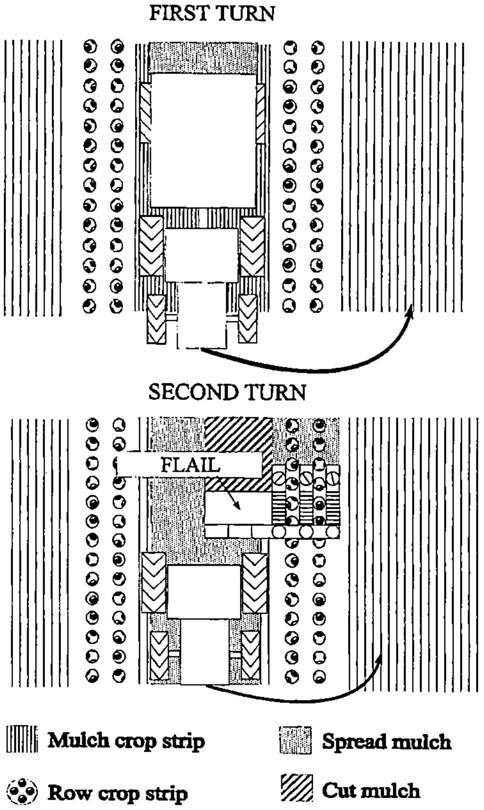


Figure 28: Technique C, combination of technique A and technique B

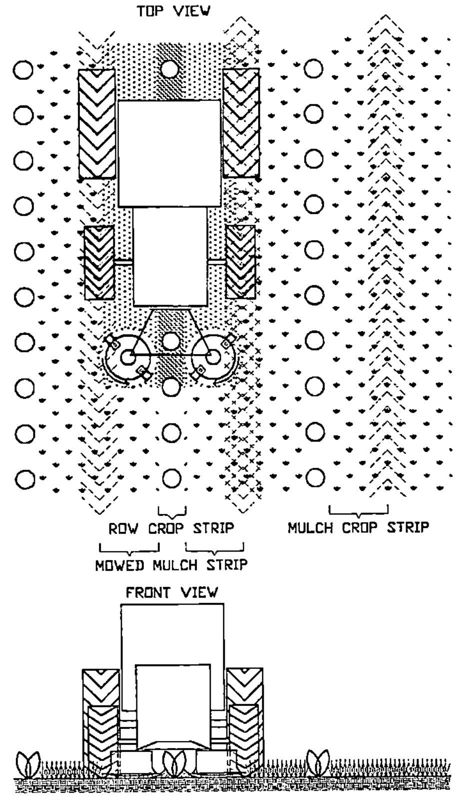


Figure 29: Technique D, modified disc mower

5.2.1 Calculation of working time

Working time and field efficiency was calculated using the following equations:

$$t = 12 * (b * v)^{-1}$$

and

$$\text{field efficiency} = t^{-1}$$

where

t	h ha^{-1}	working time
b	m	width
v	km h^{-1}	speed

The factor 12 takes into consideration time losses e.g. turning at the end of the plot and unit conversion. Other input data are listed in **Table 1** and the calculation results are shown in **figure 30**.

Table 1: Input data for calculating working time. Technique A = modified manure spreader, technique B = modified flail, technique C = combination of A and B and technique, D = modified disc mower.

Implement	Variable			Technique
Rotary tiller for seedbed preparation of the row crop	Width	2.0	m	A
		1.2	m	B, C
	4 x 0.3 m =	1.2	m	D
	Speed	5.0	km h^{-1}	A, B, C, D
Flail for harvesting green mulch	Width	1.2	m	A, B
	Speed	5.0	km h^{-1}	
Modified manure spreader	Capacity	3.9	t	A, C
	Spreading width	2.0	m	
	Speed while spreading	3.6	km h^{-1}	
Modified flail	Width	1.2	m	B, C
	Speed	2.0	km h^{-1}	
Modified drum/disc mower	Width	1.2	m	D
	Speed	5.0	km h^{-1}	

The calculation does not include work steps like tillage, sowing, planting, and harvest, which are the same for all compared techniques.

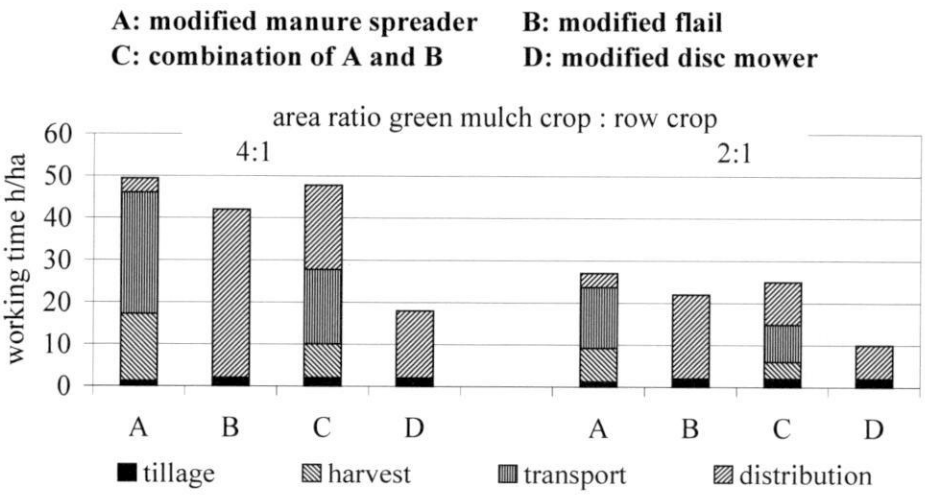


Figure 30: Working time required for the different spreading-techniques

5.2.2 Rating of process criteria

The following process criteria of the different techniques were rated: time for spreading, time for transport, dependencies related to green mulch crop and row crop cultivation, timeliness and quantity of green mulch, restrictions concerning crop rotation, suitability for common machines, traffic on row crop plot, traffic on green mulch crop plot, evenness of spread green mulch, weed control within the row, nutrient losses during transport, and use of weeds as green mulch. Rating was done by giving credits to each criterion. No problem adds 2 credits, fair 1 credit, problems cuts down 1 credit, and severe problems subtract two credits. Additionally each criterion was weighed according to its importance: Very important criteria count fourfold, important ones double. By multiplying the corresponding weight of each criterion with the maximum credit of +2 (no problem), and calculating the total of all criteria the theoretical maximum is 76 credits for the ideal technique. Rating was done according to own experiences (technique B and C) and information obtained from literature (technique A, B and C). Because technique D is not tested yet, rating bases upon assumptions.

Table 2: Rating of the advantages and disadvantages of different green mulch spreading-techniques. Technique A = modified manure spreader, B = modified flail, C = combination of A & B, D = modified disc mower, H = handwork. Rating: +2 = no problem, +1 = fair, 1 = problem, 2 = severe problem. Weight: 4 = very important, 2 = important, 1 = has regard.

Criterion Technique	A	B	C	D	H	Weight
Time required for spreading	+2	+1	+1	+2	-2	4
Time required for transport	-2	+2	-1	+2	-1	4
Independence between green mulch and row crop	+2	-2	+2	-2	+2	4
Availability of green mulch	+2	-1	+2	-1	+2	4
Independence in crop rotation	+2	-1	-1	-1	+2	4
Use of common machines	+1	-1	-1	-1	+2	2
Loss of nutrients because of self-heating	-1	+2	-1	+2	-1	1
Traffic on row crop plot	-2	+2	+2	+2	+1	4
Traffic on green mulch crop plot	-1	-1	-2	-1	-1	2
Evenness of green mulch cover	-1	+1	+1	+2	+2	4
Suppression of weeds within the row	-1	+1	+1	+2	+2	4
Weeds used as green mulch		+2	+2			1
Rating (max = 76)	7	12	23	22	33	

5.2.3 Cost calculation

Cost calculation considers the variable costs of implements, tractor, and work based on AMMAN 1997. Annual fixed costs of machines refer to 10 ha row crop. Other production costs (sowing, planting, tillage, harvest, buildings, and land) are similar to all techniques and remain outside of comparison. Input data are listed in **Table 3** and the calculation results are shown in **figure 31**.

Table 3: Input data for calculating cost. Technique A = modified manure spreader, technique B = modified flail, technique C = combination of A and B and technique D = modified disc mower.

Implement	Fixed cost	Variable cost	Technique
Rotary tiller for seed bed preparation of row crop,			
2.0 m	3640.- mk/a	112.- mk/ha	A,
1.2 m	2424.- mk/a	109.- mk/ha	B, C
Strip rotary tiller, 4 rows	9796.- mk/a	157.- mk/ha	D
Flail	3507.- mk/a	11.- mk/trip	A, C
Modified manure spreader	8618.- mk/a	21.- mk/trip	A, C
Modified flail	3863.- mk/a	24.- mk/ha	B, C
Modified disc/drum mower	5210.- mk/a	45.- mk/ha	D
Tractor, 60 kW		59.- mk/h	A, B, C, D
Work		30.- mk/h	A, B, C, D

A: modified manure spreader **B: modified flail**
C: combination of A and B **D: modified disc mower**

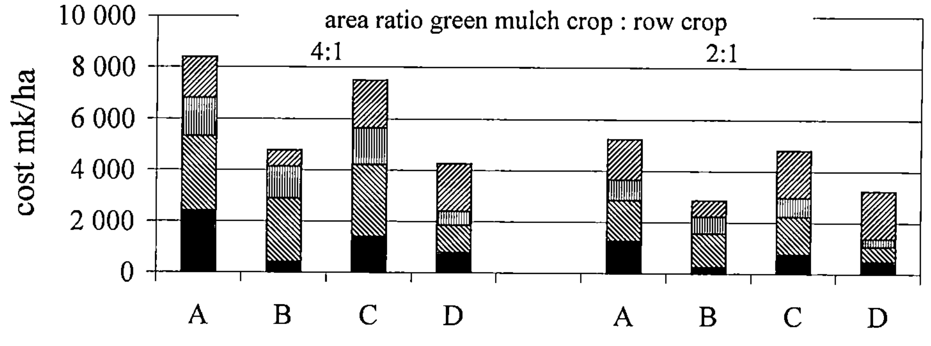


Figure 31: Cost of different green mulch spreading-techniques depending on area ratio green mulch crop : row crop

5.3 Results and discussion

The result of the evaluation of the spreading-techniques A, B, C, D, H is shown in **table 4**. Reference base of comparison is technique A, which is set to 100% for each of the three evaluation methods respectively.

Table 4: Results of the evaluation referred to technique A. Technique A = modified manure spreader, technique B = modified flail, technique C = combination of A and B and technique D = modified disc mower.

Technique	A	B	C	D	A	B	C	D
	Area ratio green mulch crop: row crop							
Evaluation method	4:1				2:1			
Costs:		%				%		
Implement costs	2397 mk = 100	17	58	33	1254 mk = 100	20	60	38
Tractor costs	2918 mk = 100	85	97	36	1593 mk = 100	82	92	37
Work costs	1482 mk = 100	85	97	36	809 mk = 100	82	92	37
Total variable costs	6797 mk = 100	61	83	35	3657 mk = 100	61	81	37
Fixed costs per 10 ha/a	1577 mk = 100	40	117	117	1577 mk = 100	40	117	117
Total	8373 mk = 100	57	89	51	5233 mk = 100	54	92	61

Table 4 shows that the advantages and disadvantages of the different techniques correspond closely with the variable cost and the working time required. Spreading by hand will need about 1 minute m^{-2}. This is about 170 h ha^{-1} and is not suitable for large-scale production.

The modified manure spreader technique is costly and time consuming and cannot be recommended especially for row crop cultures. Although the independence between green mulch and row crop cultivation is in favour of this technique, the problems caused by transport and traffic on the row crop plot predominate.

The modified flail solves the problems of the modified manure spreader in respect of transport and traffic on the row crop plot, but the price is a more difficult crop management. Although it is faster and cheaper than the modified manure spreader, the field efficiency is still too low and the prototype works unreliably under all circumstances especially when spreading red clover. The most severe problem is the dependency between the green mulch crop and the row crop, which influences the availability of green mulch and the optimum timing of mulching.

The combination of both techniques mentioned above solves this problem and collects the most credits. However, the level input of time and money is high.

The modified disc mower seems to be a very interesting solution as far as time and money are concerned. On the other hand, this technique is faced with the same problems as the modified flail with regard to the dependency between green mulch and row crop. However, this problem and the choice of suitable green mulch crops are rather a cultivation problem than a problem of mulching machines. The feasibility of technique D was recently proven by successful use of the row-mulching machine of Fischer Ltd. in wide row spacing experiments with cereals described in chapter 3.3.

5.4 Conclusions

First attempts using different techniques for green mulch spreading in row crops show encouraging results but it must be admitted that a final reliable working solution is not yet found and all techniques considered here do not achieve the quality of hand work. The modified flail allows for the performing of experiments using different green mulch crops and/or mixtures of green mulch crops to a larger extent. Mixtures of green mulch crops are very interesting. Green mulch crops like rye or reed canary grass with high fibre content establish a durable mulch cover whereas legumes of high nitrogen content serve as an efficient nitrogen source. Close co-operation between both plant production scientists and agricultural engineers is necessary to proceed successfully.

6 EXPERIMENTS WITH GREEN MULCH

The aim of the experiments was to test the prototype machine in praxis and to gather experiences with green mulch strip intercropping technique. Further, we tried to answer the question, whether spreading of green mulch may substitute mineral fertiliser and chemical weed control.

First experiments using the green mulch spreading-machine (technique B, described in chapter 4) started 1995 in Peipohja. Red clover was used as green mulch crop and cabbage as row crop with an area ratio green mulch crop : row crop of 1 : 1. It soon became clear, that distribution of wet red clover was not successful when using the green mulch prototype machine. Because of friction within the channels the cells of young and wet red clover were damaged so much, that the chopped material was mashed. Finally, the experiments failed because of an infection of clubroot *Plasmodiophora brassicae*.

6.1 Experiments in 1996 with cabbage

In 1996, the effect of different green mulch crops on cabbage in terms of green mulch quantity and timing of spreading was a subject of interest. The idea was to get information about the optimum area ratio green mulch crop : cabbage and the suitable frequency of mulching. We also wanted to gather experience of different green mulch crops and green mulch crop mixtures suitable for the prototype green mulch spreading-machine.

6.1.1 Practical tests using the green mulch spreading-machine

6.1.1.1 Material and methods

In 1996 at four different fields of the organic research farm of Agricultural Engineering Research Unit in Olkkala one trial block was prepared respectively. Each block included two green mulch crop strips and between them one cabbage *Brassica oleracea var. capitata* variety Lennox F_1 strip. The three-channel green mulch spreading-machine was used with following green mulch crop mixtures:

- field 1: mixture of rye *Secale cereale* rye and red clover *Trifolium pratense* variety Bjursele as green mulch applied at cabbage with 4 variants of area ratio and timing of spreading
- field 2: mixture of alfalfa *Medicago sativa* variety Vertus 15 kg ha^{-1} and timothy *Phleum pratense* variety Alma 6 kg ha^{-1} as green mulch applied to cabbage with 6 variants of area ratio and timing of spreading
- field 3: mixture of red clover variety Bjursele 6 kg ha^{-1}, timothy 12 kg ha^{-1} and meadow fescue *Festuca pratensis* 4 kg ha^{-1} as green mulch applied at cabbage with 4 variants of area ratio and timing of spreading
- field 4: reed canary grass *Phalaris arundinacea* variety Motterwitzer sown on one side and red clover grass (same mixture as on field 3) sown on the other side of the cabbage strip.

Each block was about 20 m long. The cabbage strip was 1.2 m wide and the two green mulch crop strips were 3.6 m wide. Green mulch crops were sown in 1995 except reed canary grass, which was sown 1993 on a whole field. The mass of spread green mulch was recorded as well as cabbage yield. The entire growing period was photographically documented. **Tables 5-8** show actions and observations using rye and red clover as green mulch and **figure 32** shows selected photographs. **Table 9** shows actions and observations using reed canary grass and red clover as green mulch and **figure 33** shows selected photographs. **Table 10** shows actions and green mulch mass using alfalfa grass as green mulch and **figure 34** shows selected photographs. **Table 11** shows actions and green mulch mass using red clover grass as green mulch and **figure 35** shows selected photographs.

Table 5: Rye, variant 1

Date 96	Action	Remarks
22.4.		Rye/clover was sown at the end of August 1995. Growth of clover is poor
12.6.	Preparing the plot with rotary tiller, 10 cm depth, 1.2 m wide. Planting of cabbage	2 rows, 55 cm row distance, 20 cm distance within row
25. 6.	Spreading, area ratio 6:1, no mowers used because of soft soil, 1978 g m^{-2} or 921 g m^{-2} dry matter. Green mulch grew about 259 g m^{-2}	Spreading no problem, rye makes a very good green mulch cover, water content 53%. Green mulch losses caused by the machine is 40.8%
3.7.		Green mulch cover still strong
12.7.		Green mulch cover still strong, first weeds visible, untreated plots show beginning growth of weeds. Because of heavy rain fall, no traffic possible
22.7.		Green mulch cover mineralising, cabbage shows yellow leaves
29.7.		Weeds grow vigorously
9.8.		Cabbage, weeds, and green mulch (both rye and clover) grow vigorously. Good timing for mulching passed
27.8.		Weeds rise above cabbage
27.8.	Spreading, area ratio 6:1, using the mowers in direction north - south. 1644 g m^{-2} or 625 g m^{-2} dry matter	Green mulch spreading-machine works very well, water content 62 %
16.9		Cabbage shows many yellow leaves, growth is irregular, clover is mineralising
8.10.	Harvesting of the best 2 m	11 cabbage heads, 2.1 kg, that is 191 g/head, 0.87 kg m^{-2} or 8.75 t ha^{-1}

Table 6: Rye, variant 2

Date 96	Action	Remarks
12.6.	Preparing the plot with rotary tiller, 10 cm depth, 1.2 m wide. Planting of cabbage	2 rows, 55 cm row distance, 20 cm distance within row
22.7.	Spreading, area ratio 2:1. 1560 g m^{-2} or 832 g m^{-2} dry matter	Good green mulch cover. Water content 47 %
29.7.		Weed starts penetrating green mulch cover
9.8.		Cabbage, weeds, and green mulch (both rye and clover) grow vigorous. Good timing for mulching passed
27.8.	Spreading, area ratio 2:1, using the mowers in direction north - south. 2048 g m^{-2} or 717 g m^{-2} dry matter	Green mulch spreading-machine works very well, water content 65 %.
16.9		Cabbage shows many yellow leaves
8.10.	Harvesting of the best 2 m	11 cabbage, 1.8 kg, that is 163 g/head, 0.75 kg m^{-2} or 7.5 t ha^{-1}

Table 7: Rye, variant 3

Date 96	Action	Remarks
12.6.	Preparing the plot with rotary tiller, 10 cm depth, 1.2 m wide. Planting of cabbage	2 rows, 55 cm row distance, 20 cm distance within row
22.7.	Spreading, area ratio 4:1. 2420 g m^{-2} or 1192 g m^{-2} dry matter	Very good green mulch cover. Water content 51 %
29.7.		Green mulch cover still strong
9.8.		Weeds start penetrating green mulch cover, especially within the row
27.8.	Spreading, area ratio 4:1, 3095 g m^{-2} or 959 g m^{-2} dry matter	Weeds rise above cabbage. Clover well grown. Green mulch spreading-machine works very well. Water content 69 %.
16.9		Cabbage looks poor, clover mineralised
8.10.	Harvesting of the best 2 m	9 cabbage, 2.6 kg, that is 289 g/head, 1.08 kg m^{-2} or 10.8 t ha^{-1}

Table 8: Rye, variant 4

Date 96	Action	Remarks
12.6.	Preparing the plot with rotary tiller, 10 cm depth, 1.2 m wide. Planting of cabbage	2 rows, 55 cm row distance, 20 cm distance within row
22.7.	Spreading, area ratio 3:1. 2420 g m^{-1} or 1212 g m^{-2} dry matter	Very good green mulch cover. Water content 50 %
29.7.		Green mulch cover still strong, weeds start penetrating
1.8.	Spreading, area ratio 3:1. 4160 g m^{-2} or 1206 g m^{-2} dry matter	Green mulch cover within the row is poor, high chaff-cutting length. Water content high (71%) because of clover
9.8.		Strong green mulch cover
27.8.	Spreading, area ratio 6:1, 2073 g m^{-2} or 788 g m^{-2} dry matter	Weeds start penetrating green mulch cover, especially within the row. Green mulch spreading-machine works very well, water content 62 %.
16.9		Some green mulch remained within the cabbage heads. Only few yellow leaves, best grow of all the plots
8.10.	Harvesting of the best 2 m	11 cabbage, 3 kg that is 272 g/head, 1.25 kg m^{-2} or 12.5 t ha^{-1}

a)

b)

c)

d)

e)

f)

g)

Figure 32: Application of rye/red clover on cabbage 1996, area ratio green mulch: cabbage 4:1.

a) 22.4.;
b) spreading first turn left side 25.6.;
c) spreading second turn left side 25.6.;
d) spreading second turn right side 25.6.;
e) spreading completed 25.6.;
f) 3.7.;
g) 12.7.;

h)

i)

j)

k)

l)

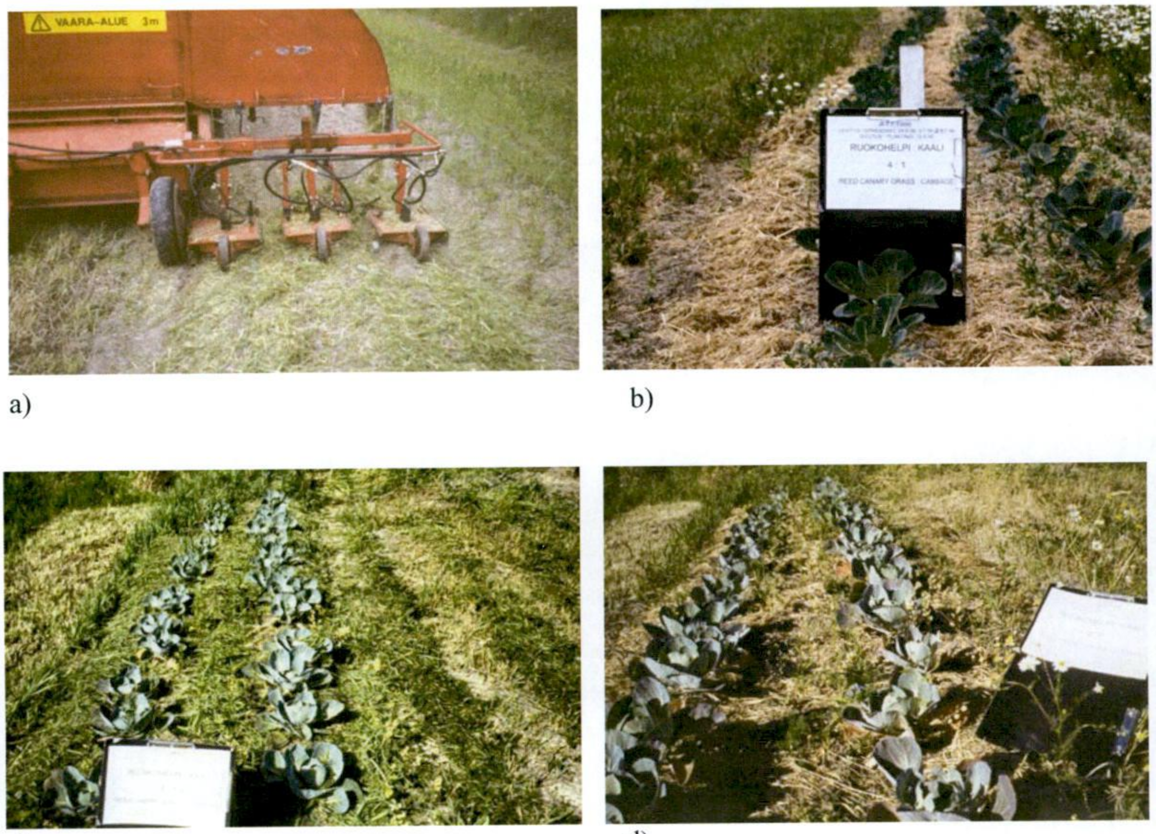
m)

Figure 32: Application of rye/red clover on cabbage 1996, area ratio green mulch : cabbage 4 :

h) 22.7.;
i) 29.7.;
j) 9.8., clover grown up;
k) 27.8.;
l) spreading second turn left 27.8.;
m) 16.9.

Table 9: Reed Canary Grass

Date 96	Action	Remarks
24.6.	Spreading, area ratio 4:1.	Green mulch grows unevenly. Innermost pipe is clogging up. Spreading is done only from the Southern side, because clover did not grow up yet.
24.6.		Mowers are working satisfactorily, although row distance of cabbage was 55 cm instead of 50 cm.
24.6.		Very good green mulch cover,
4.7.	Spreading, area ratio 2:1 using a tine.	Green mulch cover still strong, no weeds.
24.7.	Spreading, area ratio 4:1 with 700 g m^{-2} or 583 g m^{-2} dry matter.	The effect of the mowers can be detected: little green mulch between rows.
29.7.		Uncovered strips at the first row show weed growth.
9.8.		Mineralisation of green mulch cover started, weeds within the row
2.9.		Strong weed growth
2.9.	Spreading, area ratio 3:1. 822 g m^{-2} or 228 g m^{-2} dry matter	Reed Canary Grass yields low. Clover is grown up.
16.9.		No more mineralisation takes place



a) b) c) d)

Figure 33: Application of reed canary grass and red clover on cabbage 1996, area ratio green mulch: cabbage 4: 1. a) spreading of reed canary grass 24.6.96; b) 23.7.96; c) spreading 2.9.96; d) 16.9.96

Table 10: Spreading schedule of alfalfa/grass as green mulch.

Date 1996	Action	Area ratio alfalfa : cabbage	Green mulch mass g m^{-2} dry matter
7.6.	Planting		
Variant 1			
11.6.	Spreading	2 : 1	538
9.7.	Spreading	2 : 1	403
22.8.	Spreading	2 : 1	542
Variant 2			
11.6.	Spreading	4 : 1	1076
17.7.	Spreading	4 : 1	806
22.8.	Spreading	4 : 1	1126
Variant 3			
12.6.	Spreading	4 : 1	1175
17.7.	Spreading	6 : 1	795
22.8.	Spreading	6 : 1	1219
Variant 4			
12.6.	Spreading	4 : 1	1175
Variant 5			
24.6.	Spreading	6 : 1	1065
19.7.	Spreading	6 : 1	324
22.8.	Spreading	6 : 1	1509
Variant 6			
24.6.	Spreading	3 : 1	541
19.7.	Spreading	6 : 1	450
23.8.	Spreading	2 : 1	612
24. and 25.9.	Harvest		

a)

b)

Figure 34: Application of alfalfa grass on cabbage 1996, area ratio green mulch : cabbage 4 : 1.

a) 17.6.1996;
b) 3.7.1996;

c)

d)

e)

f)

g)

h)

i)

Figure 34: Application of alfalfa grass on cabbage 1996, area ratio green mulch : cabbage 4 : 1.

c) 15.7.1996;
d) 17.7.1996;
e) 9.8.1996;
f) 22.8.1996 before spreading;
g) 22.8.1996 spreading;
h) 22.8.1996 after spreading;
i) 18.9.1996

Table 11: Spreading schedule of red clover/grass as green mulch.

Date 1996	Action	Area ratio alfalfa : cabbage	Green mulch mass g m^{-2} dry matter
7.6.	Planting		
Variant 1			
1.7.	Spreading	2 : 1	662
24.7.	Spreading	2 : 1	541
Variant 2			
17.7.	Spreading	2 : 1	294
Variant 3			
22.7.	Spreading	4 : 1	784
Variant 4			
1.7.	Spreading	2 : 1	662
24.7.	Spreading	4 : 1	793
24. and 25.9.	Harvest		

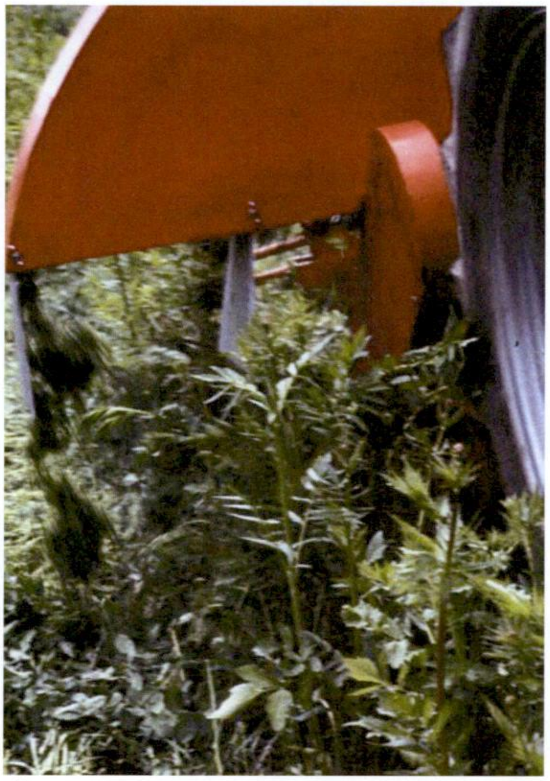
a) b) c)

Figure 35: Application of red clover grass on cabbage. Spreading 1.7.1996; b) 3.7.1996; c) 1.7.1996;

d) e) f) g) h) i)

Figure 35:Application of red clover grass on cabbage. d) 25.7.1996; e) 12.8.1996; f) 27.8.1996; g) 4.9.1996 before spreading; h) 4.9.1996 after spreading; i) 18.9.1996

The two-channel green mulch spreading-machine was used for spreading green mulch to various leaf- and root-herbs. The same green mulch crop mixture as on field 3 was used. The fields accommodated, beside the clover grass, one row of burdock *Arctium lappa*, valerian *Valeriana*, peppermint *Mentha piperita,* anise hyssop *Agastache foeniculum,* and stinging nettle *Urtica dioica planted 1995*. No clogging up of the channels occurred. Figure 36 shows the spreading of red clover green mulch in different herbs. From the herb fields, no data records are available.



a)

b)

c)

d)

Figure 36: Spreading of red clover grass in herbs. a) valerian; b) anise hyssop; c) burdock 17.6.96; d) burdock after spreading 24.8.96

6.1.1.2 Results

In 1996 the weather was extremely cold and wet during spring and beginning of summer. August was extremely dry and warm; **figure 37** shows the weather record of 1996.

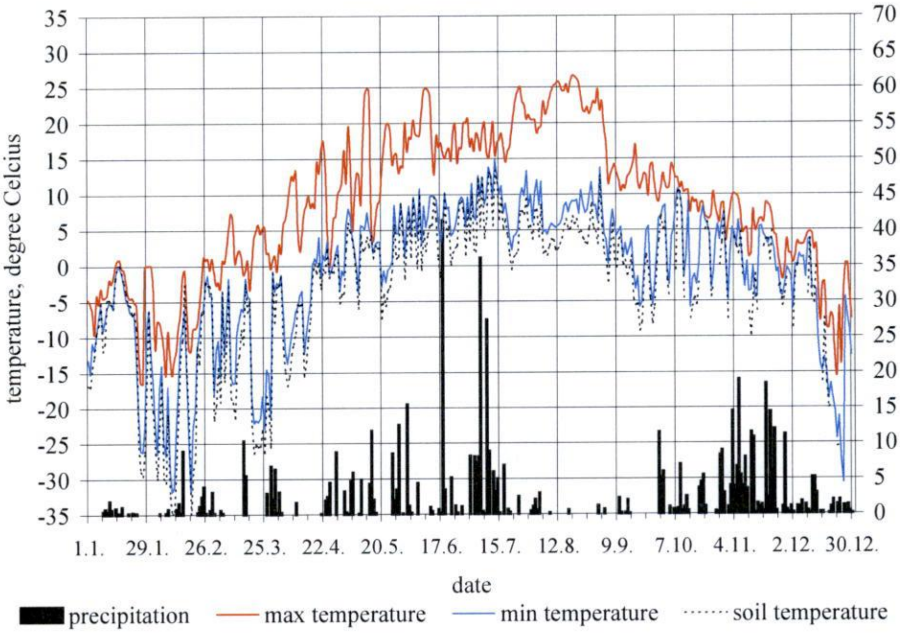


Figure 37: Soil temperature, maximum and minimum temperature, precipitation 1996 (January-May precipitation from Jokioinen)

The results in terms of yield depending on green mulch crop, green mulch mass, and mulching frequency for all plots are presented in **figure 38-40**. The last spreading on 2nd September is excluded because there was probably no longer any effect on cabbage growth.

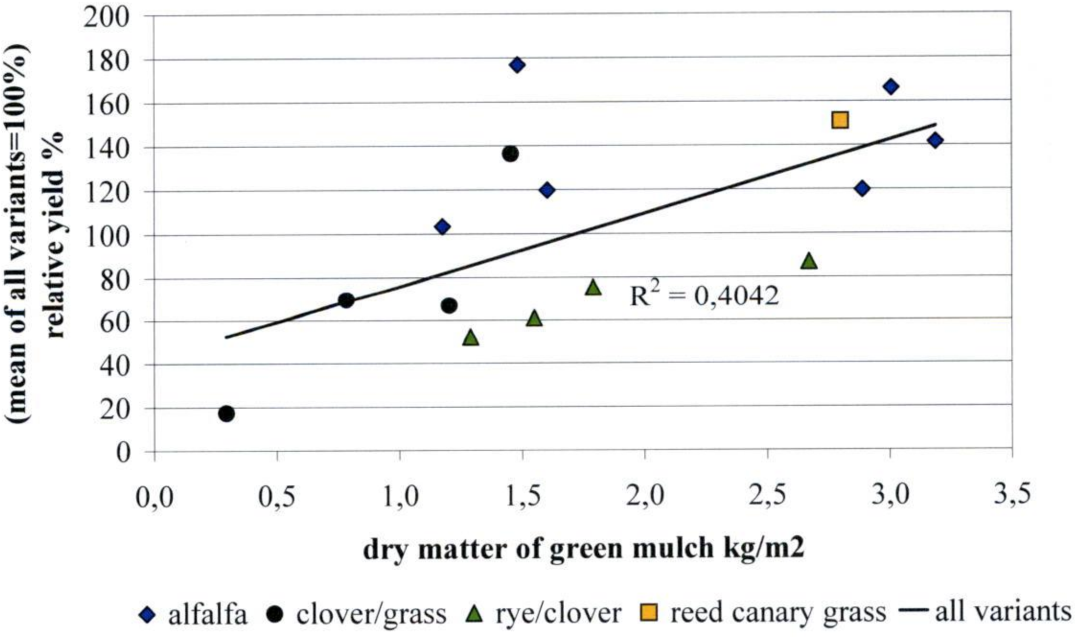


Figure 38: Fresh yield of cabbage depending on green mulch crop and green mulch mass.
100% = 1435 kg/ha in 1996

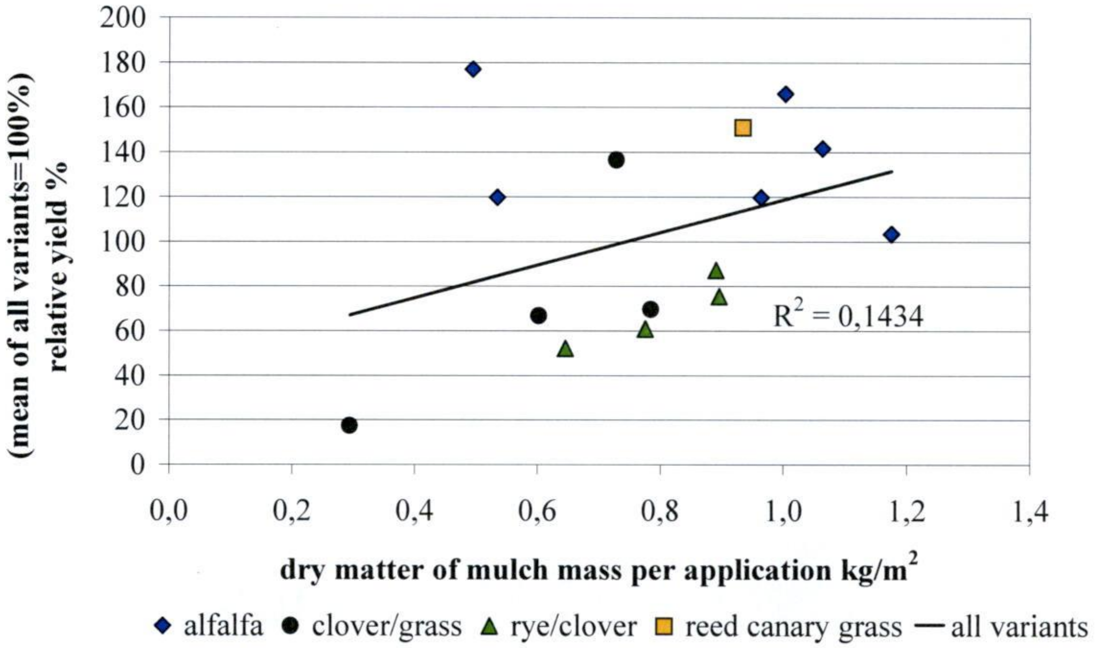


Figure 39: Fresh yield of cabbage depending on green mulch crop and green mulch mass per application. 100% = 14350 kg/ha in 1996

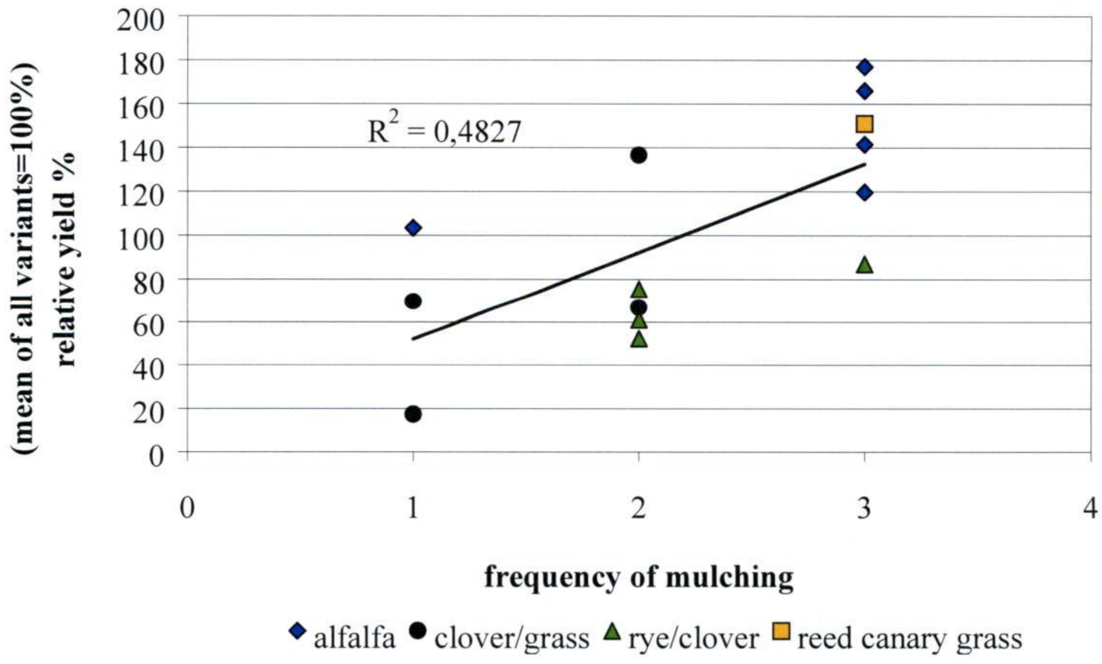


Figure 40: Fresh yield of cabbage depending on green mulch crop and green mulch mass and frequency of application. 100% = 14350 kg/ha in 1996

6.1.1.3 Conclusions

The experiences in 1996 gathered during the practical tests and documented by photographs show that

- weather conditions in 1996 granted only a three-week period of efficient green mulch application. Thus the question about best timing and frequency of mulching was not relevant because timing of green mulch spreading depended much more on soil conditions and growth of green mulch crops than on the decision of the experimenter in other words, green mulch was spread when it was possible and not when it would have been reasonable;
- all green mulch crops were suitable for the prototype machine no problems occurred during spreading. The use of a grass/clover mixture apparently avoided the bad experiences, which were had with young red clover 1995;
- persisting green mulch cover can be achieved using rye or reed canary grass;
- in 1996 the area ratio green mulch crop : row crop of 4 : 1 seemed to be sufficient for weed control;
- green mulch losses caused by the green mulch spreading-machine increase with enlarging the area ratio between green mulch crop and row crop.
- mulching effect may be improved by combining green mulch spreading with hoeing (e.g. star wheel) especially during the early growing stage of cabbage, when the application of the mowers is not feasible
- cabbage yield correlates with green mulch mass and frequency of mulching.

6.1.2 Field experiments spreading green mulch by hand

Simultaneously with the practical test of the green mulch spreading-machine described in chapter 6.1.1 Sirkka Jaakkola made mulching experiments spreading green mulch by hand. Specific quantities of alfalfa, red clover and reed canary grass were spread on a 6 x 3 m trial plot. This chapter is a summary of an unpublished research report written by JAAKKOLA & SALO (1996).

6.1.2.1 Material and methods

The experiments were designed as randomised blocks and performed at two locations with the following treatments: No green mulch, 2 x alfalfa à 1.0 kg m^{-2}, 2 x reed canary grass à 0.5 kg m^{-2}, 2 x red clover à 0.5 kg m^{-2}, and 2 x alfalfa à 0.5 kg m^{-2} dry matter respectively.

The first experiment was prepared on a block of a medium clay soil with 3-6 % organic matter located on the Kourla organic research farm of the Agricultural Engineering Research unit. The block was divided into 15 plots resulting in three replications per treatment. Each plot had a size of 10.8 m^2 containing 36 seedlings. The preceding crop was rye. The block was fertilised with Biolan hen dung containing 16.25 g m^{-2} N_{tot} and 6.8 g m^{-2} N_{min} respectively. The cabbage was planted on 7.6.1996 with a row distance of 60 cm and a plant distance within the row of 50 cm. The plots of the second and third replication were planted again on 14.6.1996 because there was different variety planted on 7.6. Soil samples were taken at 0-25 cm depth and 25-60 cm depth middle of July and 2^{nd} of October and N_{min} was determined. The cabbage was harvested on 24.9.1996 and dry matter measured. Nitrogen content was determined with Kjedahl method.

The second experiment was prepared on a soil containing 20-40 % organic matter located on the Kuuma farm of the Agrifood Research in Jokioinen. The block was divided into 20 plots resulting in four replications per treatment. Each plot had a size of 1 m^2 and no crop was cultivated. The preceding crop was chemical fallow. The block was harrowed on 15.5.1996.

The same green mulch material described in chapter 6.1.1 was used at both locations. To determine the required green mulch mass for spreading, samples were taken from three different squares of 1 m^2 size. They were dried for 24 hours at 105 °C and based on the calculated dry matter the required fresh green mulch mass was weighed on the field and distributed by hand.

For determination of dry matter and nitrogen content of fresh green mulch samples of the first spreading 17.7.1996 were taken. After the second spreading of green mulch 24.9.1996 only dry matter content was determined from samples of spread green mulch. Nitrogen content was estimated based on nitrogen content of green mulch spread on 17.7. and dry matter content of both samples as well as on nitrogen content of green mulch that was not yet decomposed in autumn. Samples from 20 x 20 cm squares were taken before second spreading on 17.7. and in autumn 24.9. for determination of dry matter and nitrogen content of not yet decomposed green mulch.

Weeds were identified and counted from 2 x 0.25 m^2 squares at Kourla and from 0.1 m^2 squares at Kuuma one month after first spreading. Three to four weeks after second spreading weeds were collected and weighed and dry matter content was determined.

A variance analysis was made with an MSTAT-C programme and the Tukey test was used to test differences between treatments smaller than 5%.

6.1.2.2 Results

The weather in 1996 was extremely cold and wet during spring and beginning of summer. August was extremely dry and warm, **Table 12.** Unsuitable weather conditions caused a low yield between 26-89 g m^{-2} dry matter of outer leaves and 4-46 g m^{-2} dry matter of cabbage heads, that is less than 4 t ha^{-1} fresh weight. The differences between the treatments were not significant.

Table 12: Weather record 1996 (mean values between 1961 and 1990 in parenthesis), (JAAKKOLA & SALO 1996, modified)

Farm	Kourla			Kuuma		
Station	Maasoja			Jokioinen		
	Temperature	Precipitation	Evaporation	Temperature	Precipitation	Evaporation
	°C	mm	mm	°C	mm	mm
June	13.1 (14.5)	76 39)	94 (126)	13.1 (14.3)	52 (47)	111 (148)
July	14.2 (16.0)	131 (72)	83 (116)	13.9 (15.3)	136 (80)	92 (129)
August	15.7 (14.2)	8 (82)	91 (79)	17.0 (14.3)	14 (83)	106 (90)
September	7.6 (9.5)	22 (70)	42 (35)	8.3 (9.4)	20 (65)	52 (40)

The following quantities of green mulch were distributed:

Table 13: Mass, dry matter, and nitrogen content of spread green mulch, (JAAKKOLA & SALO 1996, modified)

Spreading date	Kourla 18.6.1996			Kuuma 17.7.1996	
Treatment	Dry matter	Dry matter	Nitrogen	Dry matter	Dry matter
	g m^{-2}	%	%	g m^{-2}	%
Red clover	403	13.6	3.1	500	12.4
Alfalfa 0.5 kg m^{-2}	541	21.7	2.4	500	18.2
Alfalfa 1.0 kg m^{-2}	1084	21.7	2.4	1000	18.2
Reed canary grass	759	41.0	1.0	500	28.7

The application of green mulch spread by hand had the following effects on weed growth compared with zero plot:

Table 14: Number and *dry matter* of weed m^{-2} depending on green mulch application. Figures with same letter do not differ significantly, p=5%, (JAAKKOLA & SALO 1996, modified)

	Kourla			Kuuma			
Date	15.7.	5.8.	5.8.	15.7.	17.7.	15.8.	15.8.
Weeds	1 m^{-2}	1 m^{-2}	*g m^{-2}*	1 m^{-2}	*g m^{-2}*	1 m^{-2}	*g m^{-2}*
Zero plot	225 a	280 a	*63.3 a*	493 a	*246.8 a*	343 a	*351 a*
Red clover	214 ab	173 b	*40.3 a*	298 b	*96.5 b*	265 ab	*336 a*
Alfalfa 0.5 kg m^{-2}	215 ab	176 b	*50.3 a*	193 b	*58.5 a*	195 b	*222 ab*
Alfalfa 1.0 kg m^{-2}	77 b	27 b	*8.7 b*	20 c	*2.3 c*	20 c	*68.8 b*
Reed canary grass	111 ab	64 c	*10.7 b*	55 c	*7.5 c*	33 c	*57.5 b*

The most frequent weeds at Kourla were red nettle *Lamium purpureum*, pineapple weed *Matricaria matricarioides*, and chickweed *Stellaria media*. In Kuuma hemp nettle *Galeopsis*, field pansy *Viola arvensis*, and chickweed *Stellaria media*. Number and dry matter of weed decrease with increasing green mulch mass application. **Figure 41** shows this relationship for all treatments.

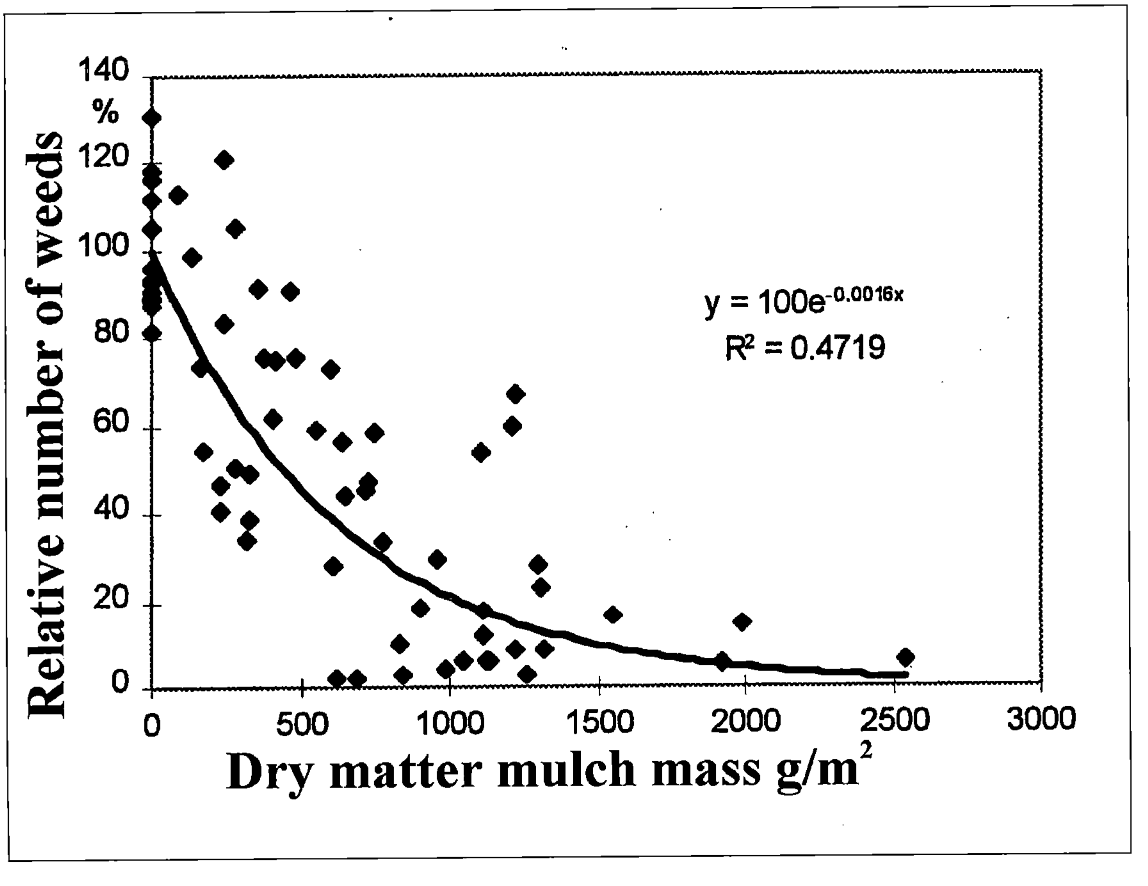


Figure 41: Relative number of weeds (100% = mean value of all zero plots) depending on spread dry matter of green mulch mass (JAAKKOLA & SALO 1996, modified)

Mineralisation of green mulch is low, even zero in reed canary grass, **Table 15**. The results confirm previous research findings (see chapter 2.2.1).

Table 15: Mineralisation of green mulch in % of spread dry matter of green mulch, (JAAKKOLA & SALO 1996, modified)

	Kourla		Kuuma	
Date	18.6.-15.7.	15.7.-24.9.	19.6.-17.7.	17.7.-24.9.
Mineralisation	%	%	%	%
Red clover	67	23	39	26
Alfalfa 0.5 kg m^{-2}	37	29	47	29
Alfalfa 1.0 kg m^{-2}	29	0	34	31
Reed canary grass	0	0	0	0

At Kourla, soil N_{min} was low. In July at 0-25 cm depth, there was 13-21 kg ha^{-1} of which 90 % was NH_4. At 25-60 cm depth, there was about 10 kg ha^{-1}. In October, there was 7-12 kg ha^{-1} and 6-10 kg ha^{-1} respectively.

In cabbage the N-content of outer leaves varied between 1.62 and 2.46 % and of the cabbage heads between 2.05 and 2.72 %. This low N-content caused a total nitrogen removal of 5-32 kg ha^{-1} by harvest.

By green mulch spreading the following N_{min} quantities were added and decomposed, **Table 16**:

Table 16: Nitrogen input and decomposition by green mulch at Kourla, (JAAKKOLA & SALO 1996, modified)

Date	Green mulch 18.6.	Decom-position 18.6.-15.7	Green mulch 15.7.	Decom-position 15.7-24.9.	Left over 24.9.
Nitrogen	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Red clover	125	-89	170	-49	157
Alfalfa 0.5 kg m^{-2}	130	-50	131	-77	134
Alfalfa 1.0 kg m^{-2}	260	-85	263	-55	383
Reed canary grass	75	0	69	0	>144

Since soil N_{min} was low and the amount of nitrogen removed by harvest was very small compared with nitrogen input by green mulch fertilisation, it must be stated, that most nitrogen of green mulch either leached (most probably between 18.6. and 15.7.) or escaped as NH_3. Reed canary grass did not show any fertilising effect; probably immobilisation of nitrogen occurred.

6.1.2.3 Conclusions

1996 was not a very suitable year for cabbage cultivation. Weed control by green mulch application worked quite well but the cabbage was not able to take up nitrogen even though mineralisation of green mulch was sufficient. Because of a wet and cold early summer all suffered: Both weed and cabbage growth was week and mineralisation of green mulch caused nitrogen losses. If 20-40 % losses by denitrification and leaching is assumed and 25-50 % is not mineralised, then only 10-30 % of green mulch nitrogen may be used as fertiliser during the growing period.

6.2 Experiments in 1997 with beetroot

6.2.1 Material and methods

In 1997, practical experiments with the green mulch spreading-machine were conducted to find out, whether green mulch application is suitable for beetroot cultivation. Alfalfa was used as green mulch crop and beetroot *Beta vulgaris var. conditiva* variety Ägyptische Plattrunde as row crop. The experiments were located at the same field as the experiments with alfalfa and cabbage of the previous year. Six plots of 12 m length were prepared 22.5. by rotary tiller four times with 20 cm working depth and 23.5. two times with 5 cm working depth. Two rows with 50 cm row distance were sown 23.5. using a one-row Nipex hand seeding machine. Seed code 1243C23 designed for beans was used resulting in 15 seeds m^{-1}. Watering was done by use of watering can and weeding was done by hand if necessary. Alfalfa was spread at different times and using different area ratio green mulch : beetroots, **Table 17**:

Table 17: Area ratio green mulch : beetroot and green mulch spreading date

Plot	Area ratio	Date
1	2 : 1	17.6., 17.7.
2	4 : 1	17.6., 17.7., 6.8., 22.8.
3	4 : 1, 6 : 1, 4 : 1, 6 : 1	27.6., 17.7., 6.8., 22.8.
4	4 : 1	27.6.
5	4 : 1, 6 : 1	27.6., 17.7.
6	6 : 1, 4 : 1	27.6., 6.8.

After spreading, the mass of green mulch was determined by collecting the green mulch from a 2 m section of the plot. The green mulch was weighed and dried. Beetroots were harvested 24.9.-26.9 and weighed.

6.2.3 Results

In 1997 the weather was extremely cold and dry between 20.5. and 8.6. nearly every night there was frost, **figure 42**. In May, there was only 15.8 mm, in June 61.6 mm precipitation. Than after, it was hot and precipitation was still smaller than evapotranspiration.

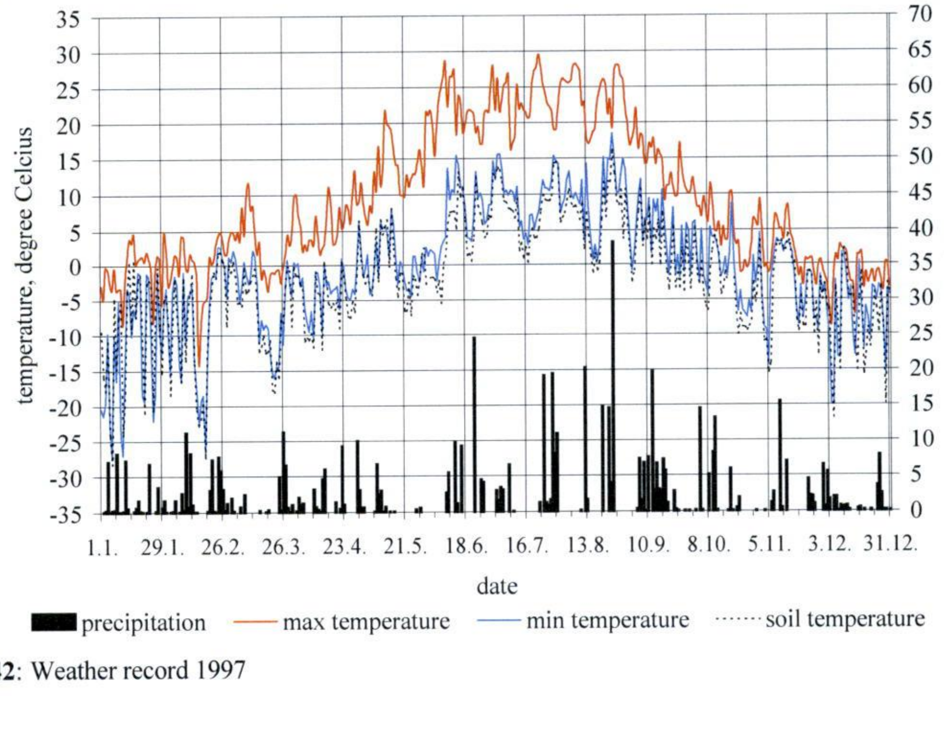


Figure 42: Weather record 1997

Unsuitable weather conditions caused reduced growth in all crops: alfalfa, beetroot, and weeds. Weed control by hand was necessary between 11.7. and 6.8., because alfalfa did not grow fast enough for second spreading but weeds grew faster than beetroots. Mainly occurred bedstraw *Galium verum*, red nettles *Lamium purpureum*, and common fumitory *Fumaria officinalis*. **Figure 43** shows experimental plot 2 before the first spreading and after spreading ten days later. 10 mm water was given two times 10.6. and 21.7. respectively. The alfalfa of plot 4 did not grow up any more after first application because it was cut very short.

Figure 43: Green mulch application with alfalfa on beetroots 17.6. and 27.6.1997

The green mulch spreading-machine worked without problems, but after first spreading 17.6. and 27.6. green mulch partly covered the small beetroot seedlings.

Beetroots were mostly very small and yield was low at all plots probably because of draught and insufficient watering. **Figure 44** shows that the yield correlated with applied green mulch mass from 0.5-1.5 kg m^2, but that higher green mulch mass had a decreasing effect.

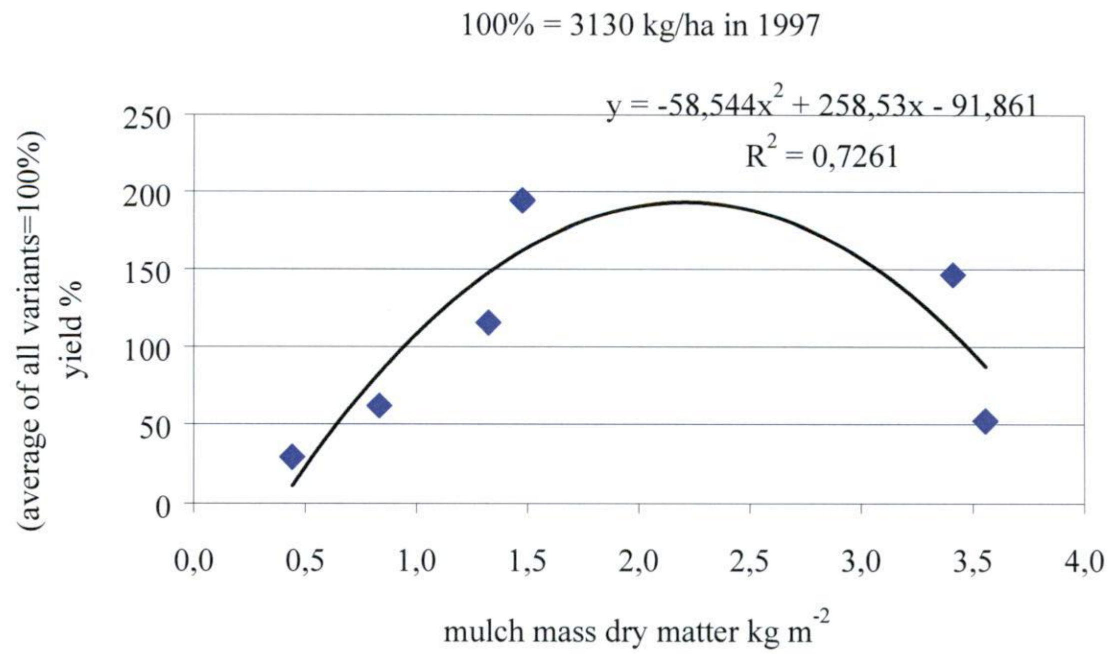


Figure 44: Yield of beetroot depending on green mulch mass of alfalfa.

6.2.3 Conclusions

The year 1997 was not very suitable for vegetable cultivation, only regular irrigation would have ensured a reasonable yield. Weed control by alfalfa green mulch application did not work, because green mulch quantities in early summer did not form a covering layer thick enough to prevent weed growth, in other words, weeds grew faster than alfalfa. One reason for this may be that the cutting height of the last cut in September 1996 was too short and weakened alfalfa growth in spring too much.

6.3 Experiments with spring cereals in 1998 and 1999

The target of the following experiments was to improve yield and quality of organic cereal production using green mulch and/or slurry as organic fertiliser. From the previous experiments, one conclusion is that the N-mineralisation from decomposing green mulch is too slow for the nutritional needs of the crop early in the summer. The early needs of the crop could be met first by row hoeing and later, as stem elongation begins, either by slurry or by green mulch application. To reach a high protein content for spring cereals also a combination of both slurry and green mulch might fulfil the requirements.

6.3.1 Material and methods

The two-year experiment comparing different mulching and/or slurry fertilisation treatments was located on the organic research farm of MTT Agricultural Engineering Research. The soil was clay of pH 6 - 6.5 and 6-12 % organic matter. In 1995 a clover meadow was established using 6 kg ha^{-1} red clover *Trifolium pratense* variety Bjursele, 12 kg ha^{-1} timothy *phleum pratense*, variety Alma, 4 kg ha^{-1} meadow fescue *Festuca pratensis*, variety Kalevi. Cuttings from the clover/grass strips should be used as green mulch. In 1997, eight strips were prepared for the cereals, each 6 m wide and 80 m long and divided into four 15 m long plots respectively. The strips were prepared mixing the clover meadow with disc harrow and rotary tiller into the topsoil. The strip distance was 6 m wide, **Figure 45**. After the snow melted the field was partially covered by water and ice for several weeks. The growth of the red clover was very poor in early spring. When spring wheat was sown 28.5.97 there was still a hope, that the red clover would recover but it did not. Red clover was sown again to the clover grass strips 18.6.1997. Lack of suitable green mulch however impeded the ability to carry out experiments. So, it was decided to harvest spring wheat and to continue with experiments in the following year.

Figure 45: Alternating wheat and green mulch strips (Photo Timo Lötjönen)

Further, it was decided to shift the cereal strips about 15 m in longitudinal direction to avoid flood damage to the red clover at the lower part of the field. As a result, the pre crop of the first block was red clover meadow whereas the pre crop of the three other blocks was wheat.

6.3.1.1 Design and operations in the field experiment

Table 18 shows the treatments of fertilisation during 1998 and 1999. All treatments were carried out on four replicate blocks. **Figure 46** shows the random distribution of the plots.

Table 18: Fertilisation treatments

Treatment	1998	1999
I	Spring wheat, zero plot	Spring barley, zero plot
II	Spring wheat + green mulch	Spring barley + green mulch
III	Spring wheat	Spring barley + green mulch
IV	Spring wheat + green mulch	Spring barley
V	Spring wheat + slurry	Spring barley + slurry
VI	Spring wheat + green mulch + slurry	Spring barley + slurry
VII	Spring wheat + slurry	Spring barley
VIII	Spring wheat + green mulch	Spring barley + slurry

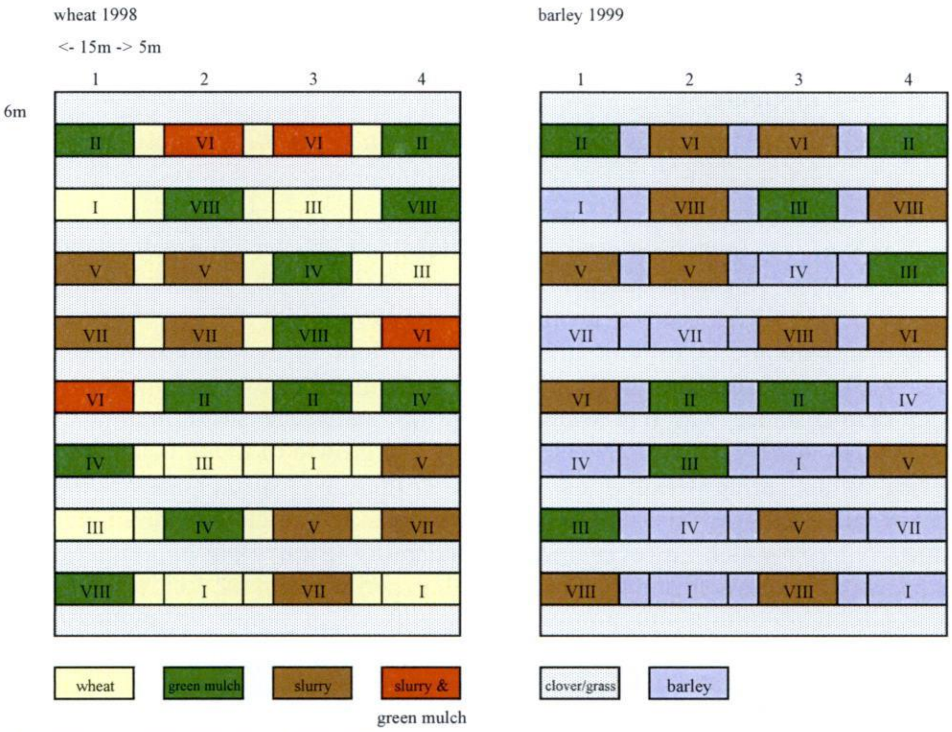


Figure 46: Random distribution of the plots

The seed bed for the spring wheat c.v. Manu was prepared 28. and 29.5.1998 with a rotary tiller and a cultivator. The cereal strips were sown (210 kg ha^{-1}) with 0.25 m row spacing. Weed control was carried out 11.6. and 7.7. using a machine hoe developed at the Agricultural Engineering Research Unit, **figure 47**.

Figure 47: Row hoe of Agricultural Engineering Research unit (Photo Timo Lötjönen)

The N-fertilisation by green mulch and/or slurry application was planned between tillering and stem elongation. In 1998 green mulch was cut and distributed 2.7. and the slurry 13.7. due to a very rainy season. The red clover strips were cut again 11.9. using a common flail to about 10 cm height and cuttings left on the green mulch strip. The wheat was harvested 21.9. by combine. Straw was chopped and distributed on the wheat strips, which were ploughed on 2.10.

In 1999, tillage began 20.5. using two times cultivator. Spring barley c.v. Artturi was sown 29.5. with 18 cm row distance and 200 kg ha^{-1}. The weed was hoed twice, 11.6. and 23.6. The slurry was distributed 16.6. The green mulch was spread 17.6. and 18.6. The barley was combine harvested 18.8.

6.3.1.2 Fertilising techniques

The green mulch was cut and distributed using the spreading-machine described in chapter 4.2. For spreading in cereals, one half of the channel system of the green mulch spreading-machine was opened. Cut green mulch left the channels at the vertex and was thrown on the cereal strip, **figure 48.** To cover the whole width of the cereal strip green mulch distribution had to be done form both sides. To ensure an area ratio green mulch crop : row crop of about 1:1 spreading was done two times at each side according to figure 27a**.** Spread green mulch mass was collected on a canopy at a 2 m long strip at the end of each plot, from which two samples were taken for dry matter determination and two samples for N_{min} determination respectively.

Figure 48: Spreading green mulch in spring wheat, 1998. (Photo Timo Lötjönen)

In 1999, the amount of green mulch was low at the time of application. Additional green mulch was chopped from another plot and transported with a manure spreader, discharged on the green mulch strip, and then distributed with the green mulch spreading-machine as described in chapter 5.1.3, figure 28.

In 13.7.1998 40 t ha^{-1} slurry was distributed by band spreading on the soil surface with a dribble hose attachment (about 80 kg N_{tot} ha^{-1}). In 1999, the slurry was distributed by watering can (about 70 kg N_{tot} ha^{-1}). Three samples were taken for N_{tot} determination. Novolab Oy in Karkkila, using the Kjeldahl method, did analysis.

6.3.1.3 Plant and soil analysis

Three sub-samples per plot were combined for the determination of cereal and straw yields. For the determination of the cereal trade quality, protein and gluten (wheat only) content a sample of 2 kg was taken. The wheat leaf chlorophyll content was measured in 9.7.1998 by Minolta SPAD-502 meter prior to fertilization.

In 1998 in each plot at tillering (12.6.), seed filling (6.8.), and before harvest (11.9.) of wheat a combined sample of six sub-samples to 25 cm deep was taken for the analysis of soil mineral nitrogen content. In barley in 1999 the soil mineral nitrogen was analysed at tillage (25.5.), before harvest (12.8.) and early winter (23.11).

Soil nitrogen determination was completed in the laboratory of the MTT Resource Management Research and the quality analysis was done in the laboratory of MTT Crop Production Research. Soluble N was determined according to MULVANEY (1996) and N_{tot} with a Leco analyser.

6.3.1.4 Statistical analysis

The mean values concerning yield, quality parameters and nitrogen contents of different treatments did not have approximately the same spread and it was not possible to correct them by transformation methods. Therefore analysis of variance was not possible and the results are statistically not significant. Thus, the following diagrams show the mean values and the minimum and maximum value to describe the trends and the wide range of parameter records.

6.3.1.5 Calculation of N-balance

- The nitrogen balance was calculated under following assumptions:
- The crop N-uptake is the sum of nitrogen content of grain (N_G), straw (N_S), and (N_R) roots. The N-content of roots is estimated to be $N_R = (N_G + N_S)\, 3^{-1}$.
- The N_{min} removal from the soil of the zero plot (N_0) is the difference between nitrogen content of soil samples of the zero plot in spring ($N_{0spring}$) and summer ($N_{0summer}$) before harvest. This amount is assumed the same for all fertilisation variants. $N_0 = N_{0spring} - N_{0summer}$
- The crop N-uptake originating from fertiliser is $N_F = N_G + N_S + N_R - N_0 - (N_{spring} - N_{summer})$
- The difference of the nitrogen content of soil samples in autumn (N_{autumn}) and at the harvest (N_{summer}) shows the amount of N mineralised after harvest (if positive) or fixated or lost (if negative) $\Delta N = N_{autumn} - N_{summer}$

The difference of the nitrogen content of soil samples in spring (N_{spring}) and (N_{autumn}) of the previous year shows the amount of N mineralised during wintertime.

6.3.2 Results and discussion

Between green mulch spreading 2.7. and harvest 22.9.1998, there prevailed a 14.2 °C mean temperature and 309 mm rainfall. Low mean temperature and abundant rainfall caused good growth of green mulch but a delay in its time of application. In 1999, a mean temperature of 17.5 °C and 85 mm rainfall predominated between green mulch spreading 16.6. and harvest 18.8.. High mean temperature and low precipitation caused poor growth of both green mulch and barley, **figure 49**:

Spreading 2.3 t ha^{-1} dry matter green mulch in 1998 corresponded to 45 kg N ha^{-1} and in 1999 2.5 t ha^{-1} corresponded to 43 kg N ha^{-1}. The green mulch partly covered the cereals causing damage and slightly lowered grain yield in both years. **Figure 50a** shows the relative yield, **figure 50b** shows the absolute figures.

In 1998, the highest grain yield was reached after slurry fertilisation. Application of green mulch plus slurry indicated that slurry compensated for the yield depression caused by green mulch fertilisation.

Green mulch application increased the proportion of weed seeds in barley. The proportion of weed seeds in barley harvested from slurry fertilised plots was 6.3 %, harvested from green mulch fertilised plots 10.1 %, and harvested from zero plots 1.69 % dry matter.

In 1998, the highest average straw yield followed slurry fertilisation while green mulch caused straw yield to be depressed. In 1999, there were no differences in straw yield between different treatments, **figure 51**.

Protein content was slightly improved from 11.8 % to 12.2 % in 1998 after green mulch fertilisation. Slurry fertiliser application resulted in 13.8 % protein content and green mulch plus slurry fertiliser in 14.4 %. In 1999, barley had a mean protein content of 14.1 - 14.2 %, independent of fertiliser treatment, **figure 52**. In addition, gluten content slightly increased under fertiliser application, **figure 53**.

Protein content and gluten correlated positively with yield on wheat 1998. The same correlation prevailed between protein and gluten content. Protein contents correlated negative on barley, which confirmed the lack of influence of fertilisation, **figure 54**.

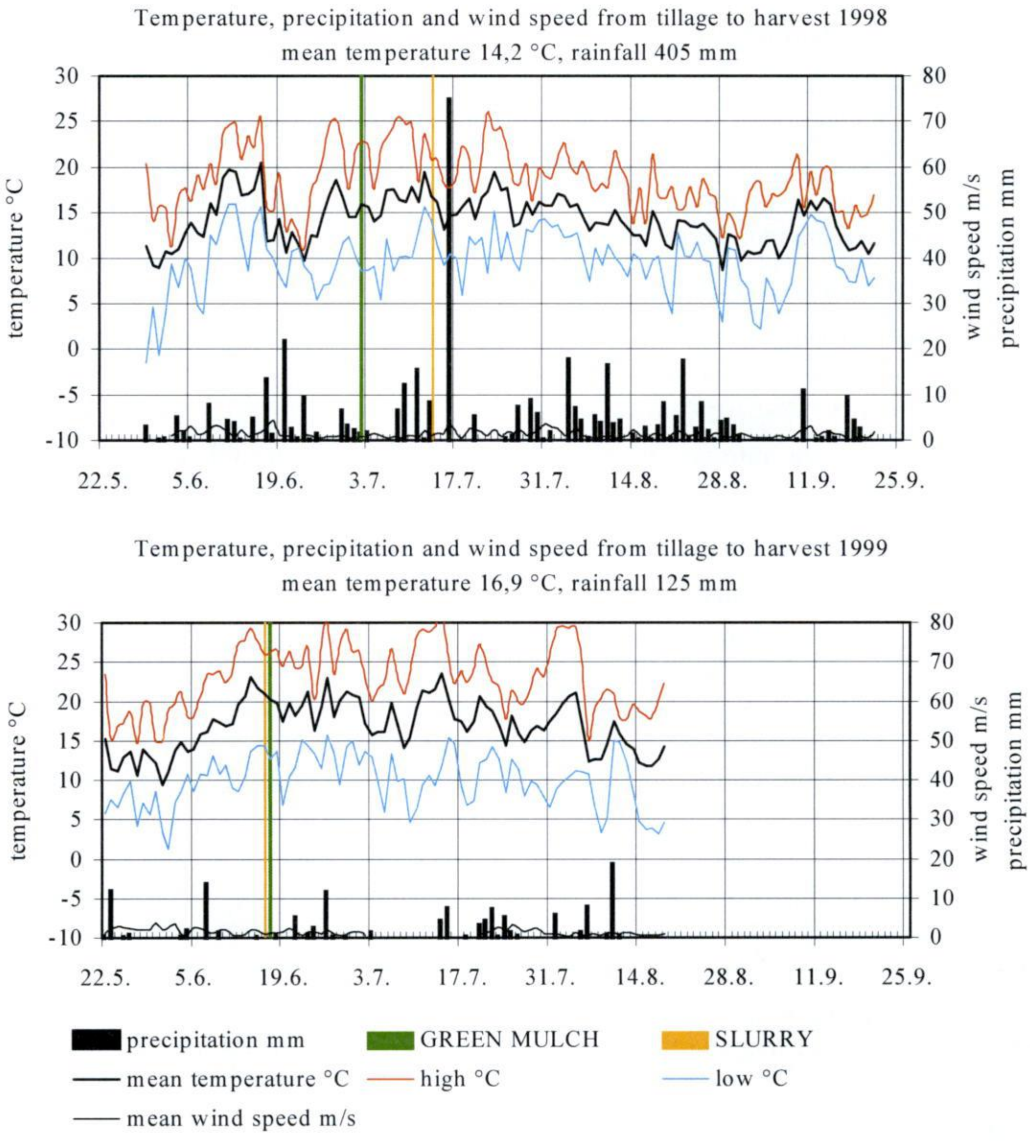


Figure 49: Weather record 1998 and 1999

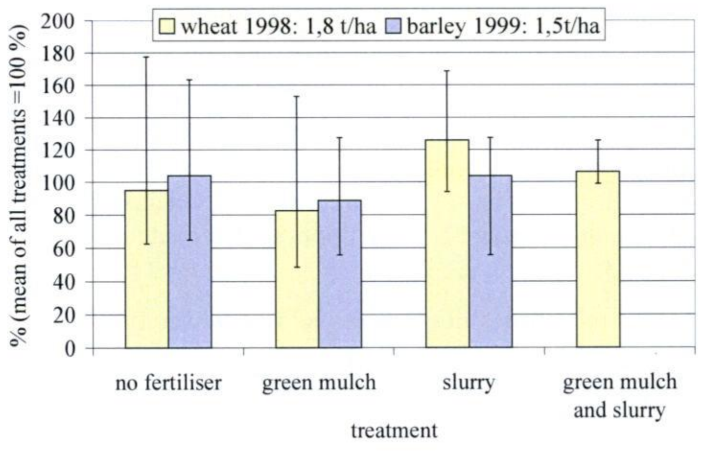


Figure 50a: Relative grain yield (min and max) in 1998 and 1999

yield of wheat 1998 kg/ha

1	2	3	4
II	VI	VI	II
?	2233	1757	1909
I	VIII	III	VIII
2033	1352	1149	1204
V	V	IV	III
2053	1696	920	1113
VII	VII	VIII	VI
3000	2083	1128	1795
VI	II	II	IV
1781	1121	863	1118
IV	III	I	V
2721	1725	1379	2296
III	IV	V	VII
3158	1944	2186	2923
VIII	I	VII	I
1888	1437	1670	1519

mean/block

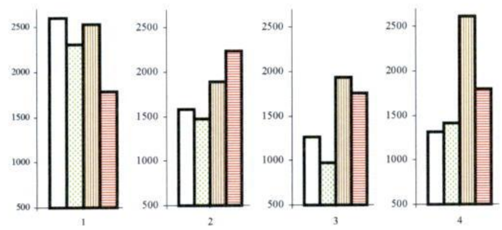
2596	1581	1264	1316
2305	1472	970	1410
2527	1890	1928	2610
1781	2233	1757	1795

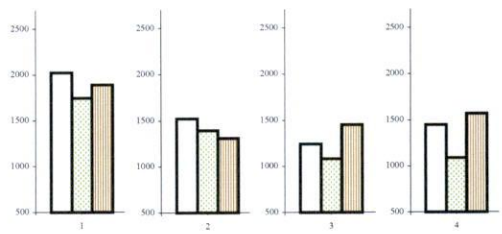
yield of barley 1999 kg/ha

1	2	3	4
II	VI	VI	II
1584	1412	1517	1340
I	VIII	III	VIII
1592	1338	987	1264
V	V	IV	III
1734	1167	974	836
VII	VII	VIII	VI
2028	1356	1171	1366
VI	II	II	IV
1734	1186	1173	1263
IV	III	I	V
2446	1599	1463	2072
III	IV	V	VII
1909	1753	1651	1839
VIII	I	VII	I
2200	1451	1287	1228

mean/block

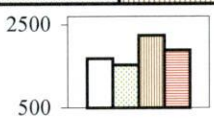
2022	1520	1241	1443
1746	1392	1080	1088
1889	1306	1447	1567





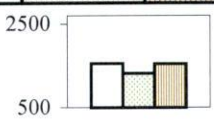
mean of all replications

1689	1539	2238	1892



mean of all replications

1557	1327	1552



green mulch + slurry
slurry
green mulch
zero plot

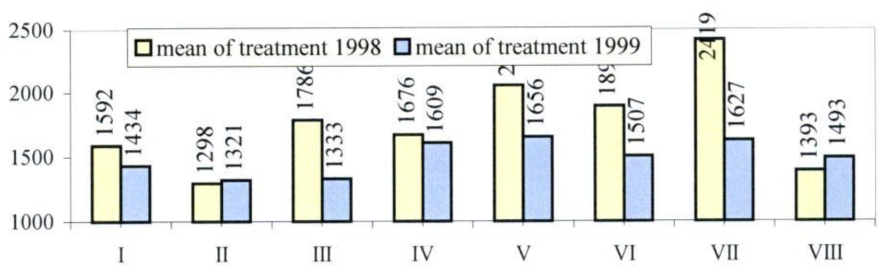


Figure 50b: Grain yield in 1998 and 1999

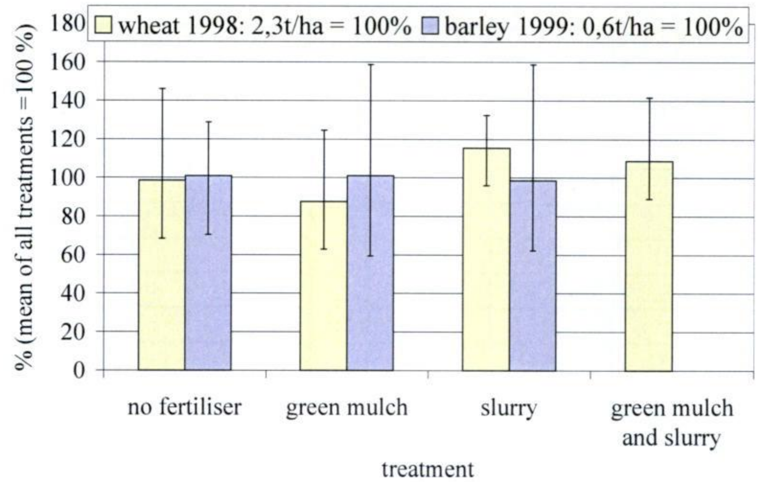


Figure 51: Relative straw yield (min and max) in 1998 and 1999

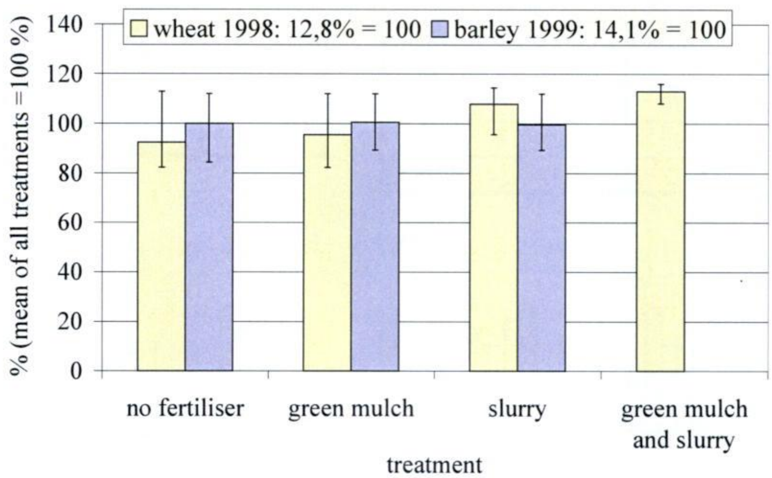


Figure 52a: Relative protein content in 1998 and 1999

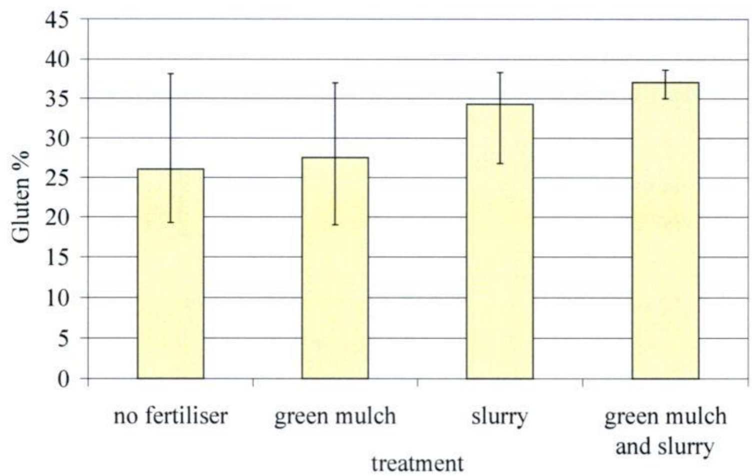


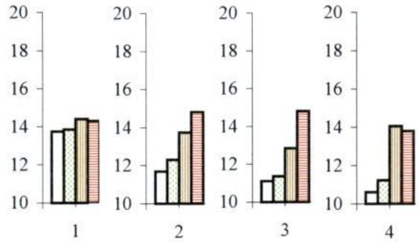
Figure 53: Gluten content of wheat protein in 1998

protein content of wheat 1998 %

1	2	3	4
II	VI	VI	II
13,8	14,8	14,8	12,6
I	VIII	III	VIII
13,1	11,9	10,7	10,6
V	V	IV	III
14,2	13,4	11,5	10,5
VII	VII	VIII	VI
14,6	14,1	11,9	13,8
VI	II	II	IV
14,3	11,8	10,7	10,5
IV	III	I	V
14,3	12,3	11,5	14,0
III	IV	V	VII
14,4	13,2	13,5	14,1
VIII	I	VII	I
13,4	11,1	12,2	10,7

mean/block

13,8	11,7	11,1	10,6
13,9	12,3	11,4	11,2
14,4	13,8	12,9	14,1
14,3	14,8	14,8	13,8



mean of all replications

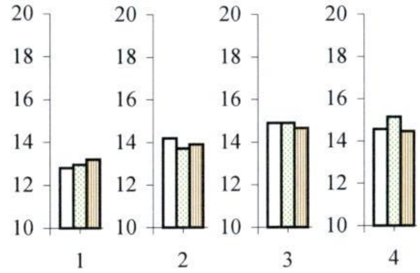
11,8	12,2	13,8	14,4

protein content of barley 1999 %

1	2	3	4
II	VI	VI	II
13,3	13,4	14,3	14,5
I	VIII	III	VIII
13,4	14,1	15,1	14,9
V	V	IV	III
13,4	14,2	15,2	15,8
VII	VII	VIII	VI
13,1	14,3	15,1	14,9
VI	II	II	IV
13,1	13,8	14,7	14,5
IV	III	I	V
11,9	13,6	13,7	13,6
III	IV	V	VII
12,6	13,6	14,6	13,4
VIII	I	VII	I
13,1	14,7	15,8	15,8

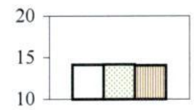
mean/block

12,8	14,2	14,9	14,6
13,0	13,7	14,9	15,2
13,2	13,9	14,7	14,5



mean of all replications

14,1	14,2	14,1



green mulch + slurry
slurry
green mulch
zero plot

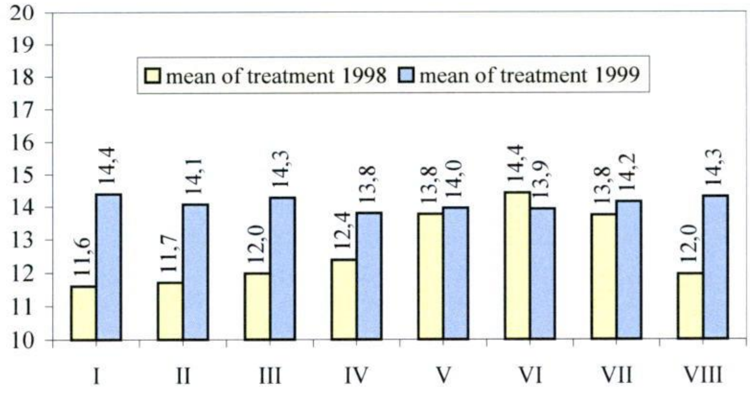
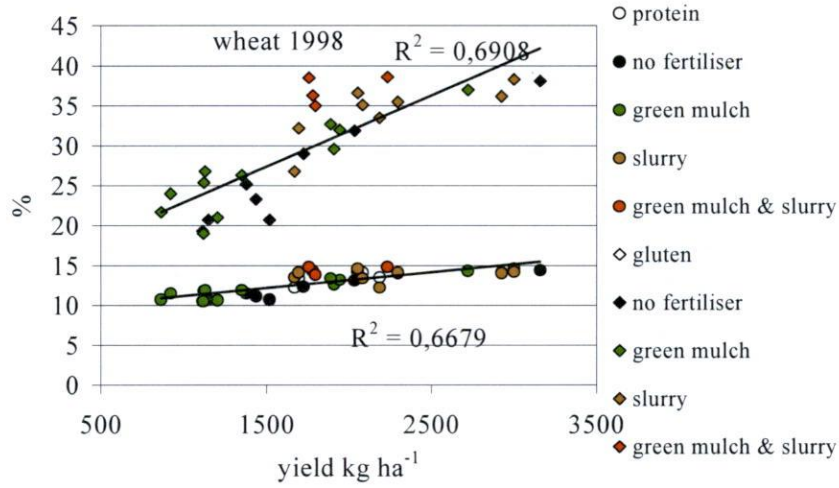


Figure 52b: Protein content in 1998 and 1999



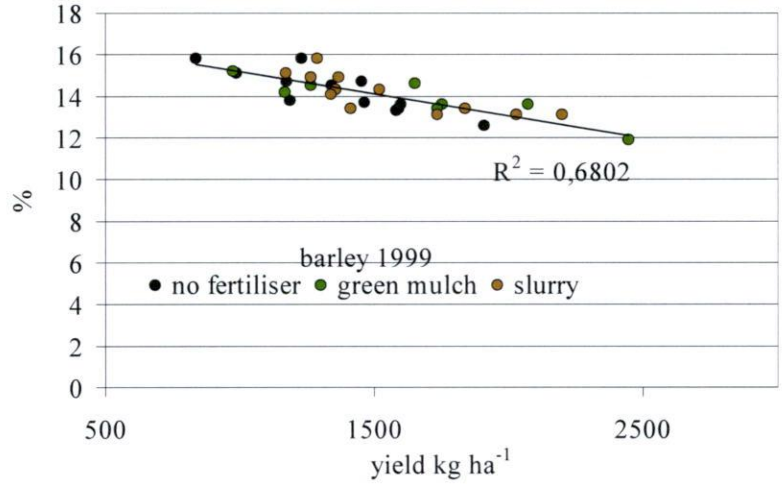


Figure 54: Correlation between protein content and yield of wheat and barley and between gluten content and yield of wheat

In 1998, the spring wheat Manu in the first replication followed clover ley while in the second, third and fourth replication the pre crop had been wheat. The clover ley as a pre crop increased wheat chlorophyll content in contrast to wheat. The difference between pre crops can be seen from **figure 55**.

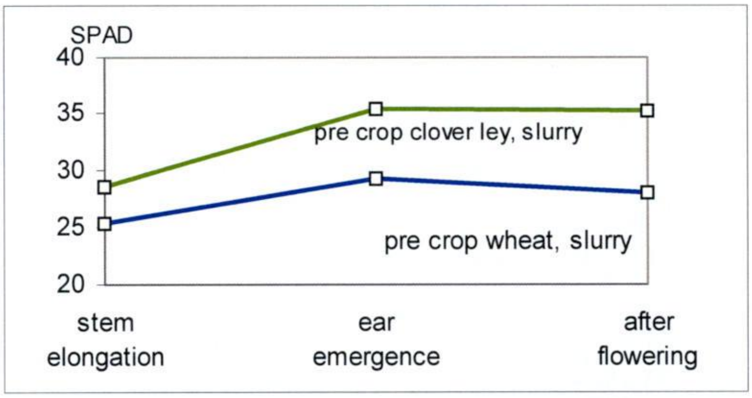


Figure 55: The effect of pre crop on the leaf colour of wheat at stem elongation, ear emergence and after flowering in the slurry fertilized plots

Slurry fertiliser application slightly improved thousand-grain weight and hectolitre weight, **figure 56** and **figure 57**. Falling number exhibited a contrasting trend, **figure 58**.

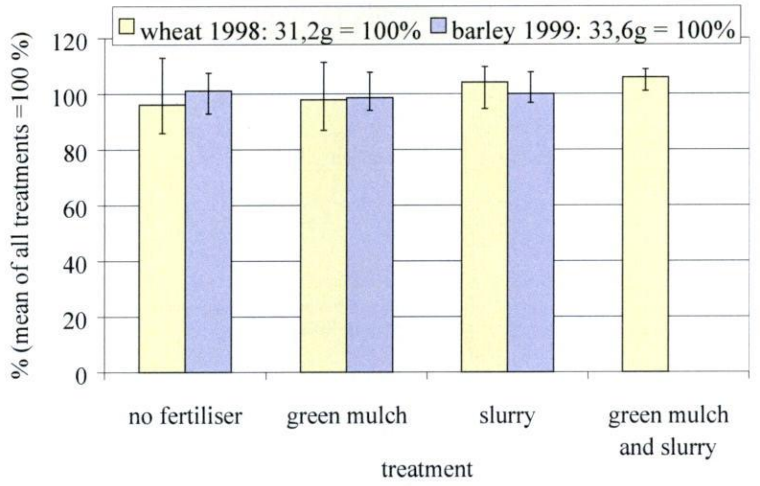


Figure 56: Relative thousand-grain weight (min and max) in 1998 and 1999

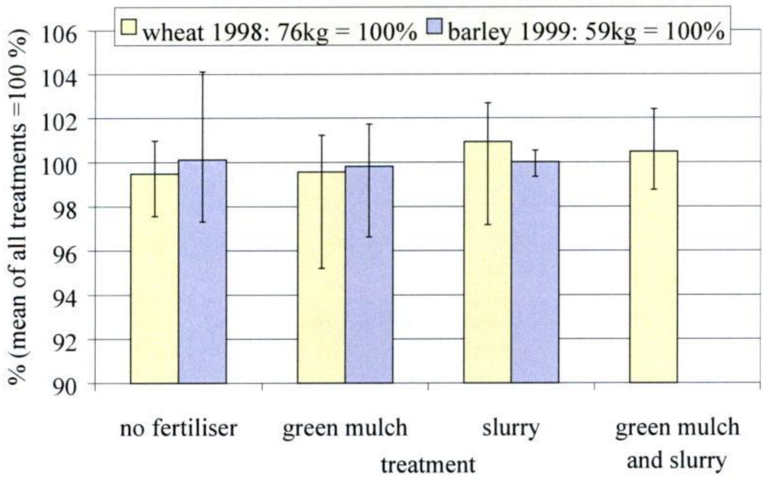


Figure 57: Relative hectolitre weight (min and max) in 1998 and 1999

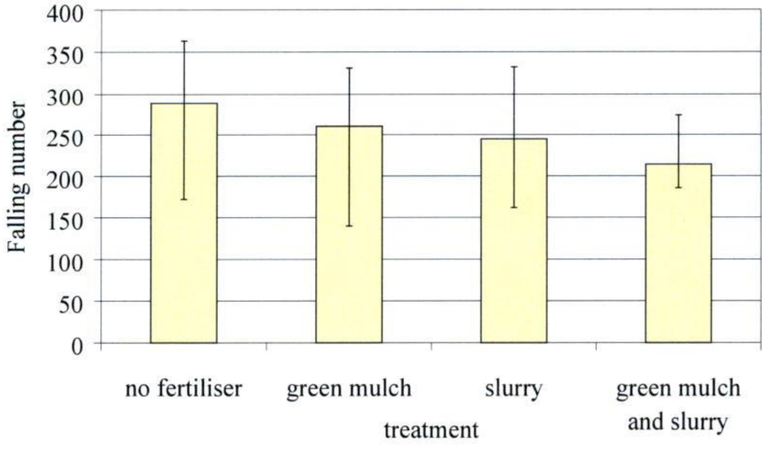
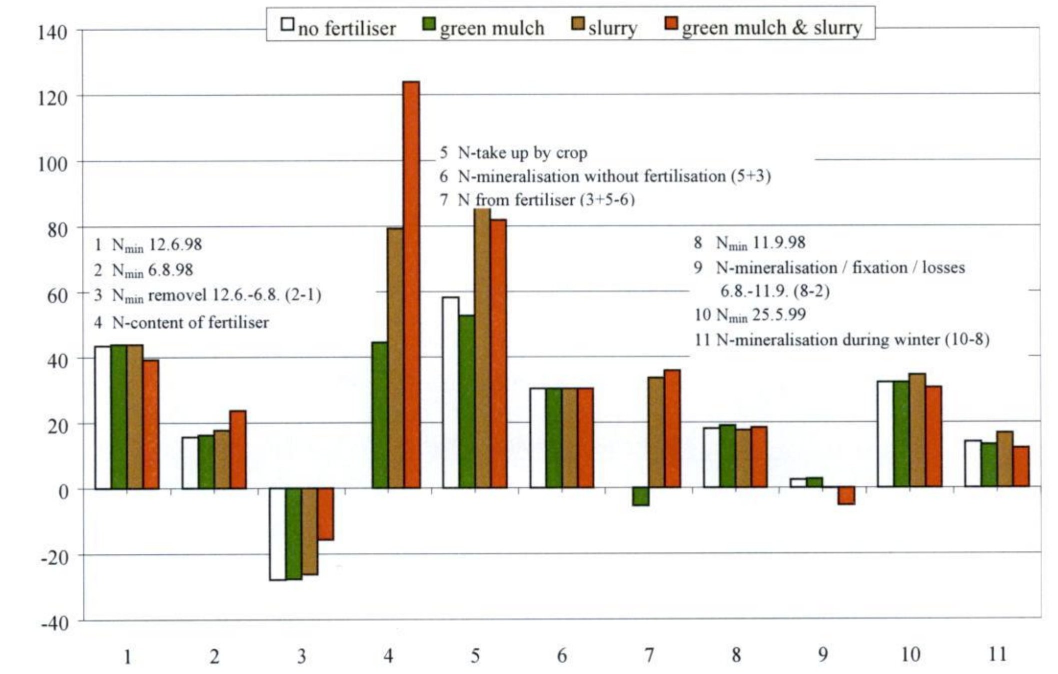


Figure 58: Falling number of wheat (min and max) in 1998

In 1998, fertilisation contributed somehow to N supply of spring wheat. In 1999, N-mineralisation was negative after harvest, but application has increased nitrogen content during growing period, **figure 59**. Perhaps it was used by weeds and it came too late. Nitrogen content of fertiliser was too low to contribute to N-supply in time.



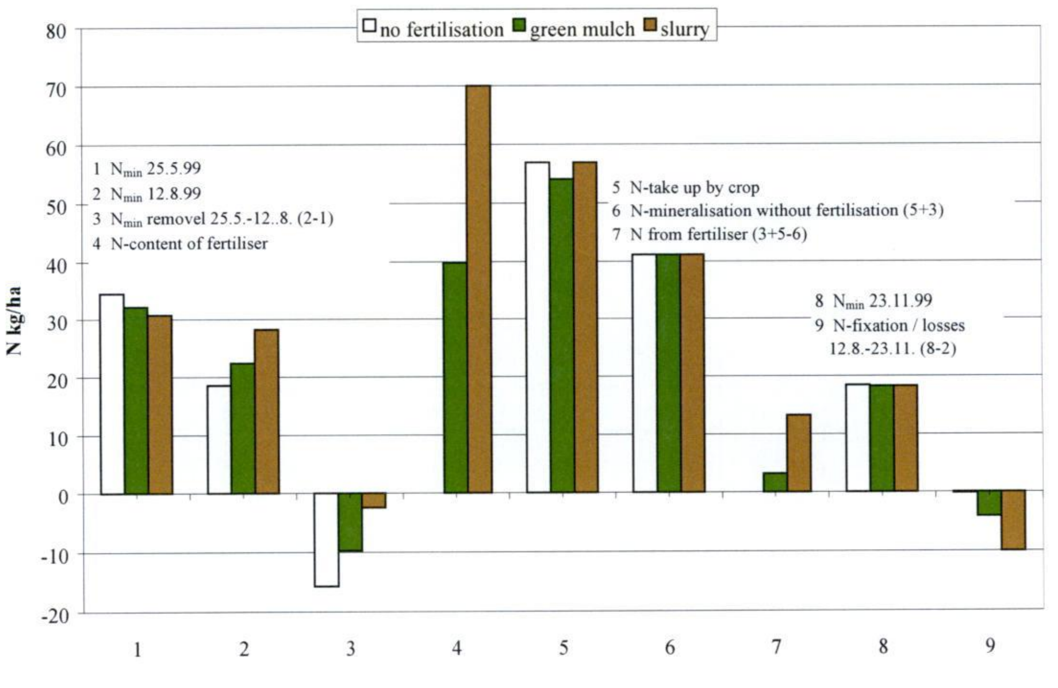


Figure 59: N-balance of wheat in 1998 and of barley in 1999

6.3.3 Conclusions

In 1998, the highest grain yield was reached after slurry fertilisation. The application of green mulch plus slurry indicated that slurry compensated for the yield depression caused by green mulch fertilisation. Green mulch application increased the proportion of weed seeds in harvested grain in the second year. In 1998, the highest average straw yield followed slurry fertilisation while green mulch caused the straw yield to be depressed. In 1999, there were no differences in straw yield between different treatments.

Protein content was slightly improved from 11.8 % to 12.2 % in 1998 after green mulch fertilisation. Slurry fertiliser application resulted in 13.8 % protein content and green mulch plus slurry fertiliser in 14.4 %. Similar trends were reflected in thousand-grain weight and hectolitre weight. The falling number exhibited a contrasting trend. The best quality wheat was harvested in 1998 following slurry application. Green mulch application slightly improved the quality. In 1999, barley had a mean protein content of 14.1 - 14.2 %, independent of fertiliser treatment. In 1999 there was no fertilising effect in either green mulch or slurry. No effect of green mulch fertilisation to the following crop was observed.

Slurry fertiliser may improve grain quality under suitable weather conditions, but the drought in 1999 probably caused nitrogen losses from both green mulch and slurry.

Green mulch fertiliser seems to be an unsuitable nitrogen fertiliser for Southern Finland. Timing of production of sufficient green mulch is unreliable. Mineralisation of green mulch is probably too slow, especially at low temperatures and during long-lasting dry periods. An area ratio of 2:1, green mulch to cereal, may ensure that the target nitrogen quantity of about 80 kg N ha^{-1} is reached.

The spreading technique does not seem to be the limiting factor since implements for an improved technique like wide row spacing in combination with green mulch cultivation are available, figure 18 in chapter 3.3.

7 CONCLUSION

The subject of this research report is green mulch spreading-technique. Handwork can be replaced by a green mulch spreading-machine for row crops developed at the Agricultural Engineering Research Unit of MTT Agrifood Research Finland.

Field experiments using the prototype machine showed that the weather factor is most dominant. Often timeliness of green mulch spreading was not possible because of wet soil conditions; often green mulch crops did not grow because of draught. The prototype worked successful with mixtures of legumes and ley crops under suitable weather conditions. However, the spreading of red clover was not possible. The prototype machine was useful for testing different cropping techniques with different green mulch crops.

The strip intercropping technique in combination with a strip mower (row-mulching machine of Fischer Ltd., see chapter 3.3) is presently the best green mulch spreading-technique if the weather conditions are suitable. Only zero traffic technology like gantry offers perfect green mulch spreading independent of weather and soil conditions. Further development, testing and evaluation of the complete mechanisation chain for green mulch application in row crop production depends mainly on following questions:

- What is the ideal green mulch crop mixture for a given row crop?
- Under which conditions does a green mulch crop mixture of high fibre content (grass) and high nitrogen content (legume) establish a weed suppressing cover
- Under which conditions does a green mulch crop mixture of high fibre content (grass) and high nitrogen content (legume) ensure timeliness of sufficient nitrogen nutrition?

- Does mulching in two layers (first layer legume, second layer grass) improve nitrogen nutrition of the row crop and decrease nitrogen losses?
- How does the number of treatments (= spreading of green mulch) influence yield and quality of the row crop?
- Does the optimum timing and the frequency of treatments mainly depend on weather conditions or growing stage of the row crop, or growing stage of the weeds, or on all these factors to the same extent?

To answer these questions the expertise of plant nutrition scientists (N-balance), legume researchers (legume species, yield depending on time and mowing frequency, raw fibre content), pest control specialists (interaction between pest and green mulch crop quantity and species) especially in the field of organic farming is required and invites collaboration.

However, even improved spreading technology does not solve the other problem, caused by weather conditions: Uncertain growth and mineralisation of green mulch. This is mainly a problem in North European countries in contrast to tropical areas, where temperature and humidity always ensure both, vigorous growth and rapid mineralisation.

In any case, a legume-rich crop rotation and organic manure from livestock would be the better alternative for fertilisation in organic farming under North European conditions if manure is available. Another alternative is the use of milled seeds of legumes, hornmeal or cake of *Ricinus communis*. For these materials traditional fertilising machines is available. The application of these organic fertilisers is not weather dependent and they can be produced and purchased far from the location of application.

The worldwide application of green mulch techniques is essential for a sustainable agriculture. Although in most tropical countries spreading is still done by hand, mechanisation of green mulch spreading will gain importance in the near future.

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54/93 Maaseudun koerakentamisen ohjelmointi

55/93 Pyöröpaalisäilörehun korjuu, varastointi ja laatu

56/93 Maaseuturakentamisen ideakilpailu

57/93 Syyskylvöjen varmentaminen

58/93 Maatilan ja maatilamatkailun jätehuolto

59/93 Maatilamyymälätoiminta vanhassa maatilan asuinrakennuksessa

60/93 Tyhjien maatilarakennusten uusi käyttö

61/94 Lietelannan varastointi ja levitys

62/94 Tuotantorakennusten alapohjia ja piha-alueiden päällysrakenteita

63/94 Turvallinen puunpilkonta

64/94 Itkupinta-tuloilmalaitteen vaikutus eläinsuojassa

65/94 Oksainen hake pienpolttimissa

66/94 Pako- ja savukaasujen analysointi

67/94 Käyttökokemuksia jyräkylvölannoittimista

67S/94 Brukserfarenheter av vältkombisåmaskiner

68/94 Käsikäyttöisten liekittimien käyttöominaisuuksia

69/95 Renkaiden vaikutus traktorin vetokykyyn ja maan tiivistymiseen

70/95 Hakkeen kuivaus imuilmalla

71/95 Klapikattiloiden käyttöominaisuudet

72/96 EPS-rakeet ja EPS-rouhe sikalan lietesäiliön katteena

73/96 Kevytsaviharkkojen kuivuminen ja lujuus

74/97 Rikkakasvien torjunta viljoista riviväliharauksella

75/97 Öljypellavan leikkuupuinti

76/97 Tilasäiliöopas

77/98 Yrttikuivurin suunnittelu ja käyttö

78/98 Väkilannoitteen sijoituslaitteet nurmiviljelyssä

79/98 Lietelannan ilmastus

80/00 Lannan aumavarastointi

81/00 Pienen pyöreän puun käyttö rakentamisessa I
Pyöreän puun lujuus, mänty ja kuusi
Pyöreän puun liitokset

82/00 Pienen pyöreän puun käyttö rakentamisessa II
Suomen rakennuspuuvarat
Rakennuspuun korjuukustannukset
Rakennuspuun tuotantokustannukset

83/00 Pienen pyöreän puun käyttö rakentamisessa III
Rakenteet, liitokset, rakennusesimerkit

84/00 Perunaviljelmän edullisin koko Suomessa
Sään rajoittama viljelytöiden aika
Viljelmien nykytila kyselyn perusteella

85/01 Lantavarastot ja pihatoiden ritiläpalkistot