Preface

This master thesis was started up in the summer of 2010, and marks the end of my studies of plant science here at the Norwegian University of Life Sciences (UMB).

I own and run a family sod production company in Norway, together with my mother and father, which is the background of my interest in doing research on sod production.

The thesis was written at the Institute of Plant and Environmental sciences (IPM). My advisors Professor Johannes Einset (UMB) and Trygve Aamlid (Bioforsk).

I would like to thank both Einset and Aamlid for giving me the opportunity to write a thesis on this topic. I would also like to thank them for discussions, and for their valuable information and knowledge on the topic, provided to me throughout the semester. I would also like to thank Trygve Aamlid for helping me with the statistical data analyses and the fieldwork we did together on the research area.

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Abstract

Research and development of sod production has been slow in Norway, compared to other countries. For the sod grower and customer alike, it would be advantageous if sod quality could be improved and the production period decreased by more intensive management. Research on this topic is limited, especially under Norwegian climate conditions. The objective of this thesis was to clarify the effect of different management practices on sod quality. More specifically, I studied the effects of fertilizer type and application frequency, as well as regular use of biochemicals during production on the quality of washed and unwashed sod of different age.

The research was carried out on a sod farm in Rygge. A three-replicate spilt-split plot trial with (1) sowing time / sod age on main plots, (2) fertilizers and (3) biochemicals on subplots and washed vs. unwashed sod on sub-subplots, . Registration of turfgrass characteristics was done continuously throughout the production period, at harvest as well as the installation period of the sod. Characteristics registered were of physical and visual assessments.

The two different ages of the sod, unfortunately differed in species composition. The young grass (seeded in September) had a majority of Kentucky bluegrass (*Poa pratensis L.*), whereas the older sod had a majority of red fescue (*festuca rubra*). The difference in species composition made it impossible to determine if the effect of sod age was a true age effect or an effect of turf grass species composition. The results showed several interactions, which means that the different factors are related. There were significant interactions under the production period, at harvest and post harvest. The results showed that replacing Fullgjødsel with liquid fertilizer would not decrease the production period. However, using Liquid fertilizer or biochemicals have the potential of increasing sod quality. Biochemicals had significant positive effects especially under stressful conditions. Liquid fertilizers had an overall beneficial effect on the mature red fescue dominated turf. On the other hand, Fullgjødsel had greater effect on the Kentucky bluegrass dominated turf, especially, when applied together with Biochemicals. Biochemicals and liquid fertilizers had positively effects individually, but the results was not additive, as the two factors interact and depended on turf age and/or turfgrass species which, in our research, unfortunately were confounded.

Sammendrag

Utviklingen ferdigplenproduksjon går sakte fremover i Norge i forhold til andre deler av verden. Kunnskap om bedre produksjonsteknikker og teknologi for å minske produksjonstid og øke kvalitet er faktorer som er viktige, både økonomisk og miljømessig. Forskning på dette området er begrenset, spesielt under norsk klima og norske vekstbetingelser. Formålet med oppgaven er å gjøre rede for effekten av forskjellig produksjonsmetoder på kvalitet av ferdigplen. Mer spesifikt undersøkte jeg effekten av gjødseltyper/regimer, samt bruk av biokjemikalier gjennom produksjonsfasen på vasket- og uvasket gress av forskjellig alder.

Et forsøksfelt ble etablert på en lettleire sommeren 2010 i Rygge, og varte frem til høsten 2011. Forsøksplanen var et split spilt plot med (1) såtid/alder på storruter, (2) gjødsel / (3) biokjemikalier på mellomruter, og senere (4) gressvasking på småruter når gresset ble høstet og lagt på et nytt sted. Det var tre gjentak. Registreringer ble gjort i produksjonsfasen, ved høsting og etter legging 16. september.

Til tross for lik frøblanding bestod det unge gresset (sådd i september) for det meste av engrapp (*Poa pratensis L.*), mens det eldre gresset (sådd i mai) hadde mest rødsvingel *(Festuca rubra).* Dette gjorde det dessverre umulig å skille mellom arts- og alderseffekter Av resultatene var det mange samspill som viser at faktorene virker inn på hverandre. Det var signifikante samspill mellom gjødseltype, biokjemikalier og alder både i produksjonsfasen, etter høsting og etter legging. Ut fra resultatene kan vi ikke si at det er mulig å redusere produksjonstiden gjennom å bytte ut fast gjødsel med flytende gjødsel eller tilføring av biokjemikalier. Men resultatene viser at biokjemikalier har potensiale til å øke kvaliteten av ferdigplen, særlig av engrapp ved korte produksjonstid. Flytende gjødsel hadde positive effekt på det eldre rødsvingel-dominerte gresset, mens fullgjødsel hadde større positiv innvirkning på det yngre engrapp-dominerte gresset. De positive effektene målt individuelt med biokjemikalier og flytende gjødsel viste seg å reagere negativt når disse ble tilført sammen.

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1 Introduction

Sod production has a long history in Europe and the rest of the world. Richter Rasen was one of the first companies to produce sod in Europe in 1906 (Richter-Rasen, 2012). At that time there was little concern about the quality of the sod. The labor was done by hand, and it was a very time consuming production. 100 years later, the industry has come up with efficient machines with capacity to harvest thousands of square meters per day. Big turfgrass companies such as the British company Rolawn cultivate over 1500 hectares of sod for the European market (Rolawn, 2012).

To maintain an efficient sod production, producers are dependent on large fields to grow and manage the turf before harvest. Prices for renting farmland for sod production vary, but because some soil is harvested together with the turf, prices tend to be higher than for regular agricultural production. Big producers with a lot of rented land will have a big expense concerning land rental. To reduce the expenses for more land, it would be beneficial for a producer to manage the turf in a way that will lead to development of high quality turf as fast as possible.

Sod production in Norway was first started by ”Norsk ferdigplen” in 1985. Since then, there have been an increasing number of producers. Today there is approximately 20 Norwegian growers, cultivating and selling over 200 ha sod every year. The turfgrass species are mainly Kentucky bluegrass *(Poa pratensis* L.*)* and red fescue *(Festuca rubra* L.*)* in a mix. There is some production of perennial ryegrass *(Lolium perenne* L.*)* and creeping bentgrass *(Agrostis stolonifera* L.*)* sold as sports turf.

There isn’t any regular education or training for sod farmers in Norway, therefore the knowledge of the production is based on experience. Some sod farmers attend international conventions where producers get together and share experiences. Ten to twenty years ago, the increasing Norwegian market resulted in import of sod, mainly from Sweden and Denmark. Because of this increase, Norwegian sod growers began to rent more land, to be able to meet the demand from the increasing market. After the season of 2008, the market dropped suddenly as a result of the international financial crisis. The decreasing market resulted in increased competition, lower prices, more focus on efficient production, and a higher focus on quality.

Successful sod production is based on efficiency and quality. The faster a producer can grow sod with acceptable quality, the less effort and energy must be put into the production. Quality can be measured in different ways. Color, number of shoots per square meter, root mass, thatch accumulation, number of weeds, and the percentage of open soil in the sod are characters that together say something about the quality of a sod (TPI, 1995).

Better quality is achieved through better management. Quality therefore depends on the tillage, what- and when you seed, pesticide use, fertilizing, moving, irrigation and harvesting. All these parameters have an impact on the quality of the product that the customer receives in the end.

Golf courses and sports fields have a higher demand on quality than people buying sod for their home lawn. Sod for these areas are often sold as thick turf or washed sod. Østfold Gress has been the only supplier of washed sod in Norway. The first sports field was Ullevaal national football arena in 1994. The objective of this production is to deliver a high quality sod, without the negative effects of the soil that comes with the product.

1.1 Objective of thesis

The objective of this thesis was to clarify the effect of different management practices on sod quality. More specifically I studied the effects of fertilizer type and application frequency, as well as regular use of biochemicals during production on the quality of washed and unwashed sod of different age. My hypothesis was that it’s possible to reduce turf production period, and enhance sod quality by replacing agricultural fertilizers with liquid fertilizers and biochemicals.

1.2 Key terms

This is a list of key terms used in the thesis. It is recommended to go through the list before reading the thesis, as terms can differ from those found in other literature.

Sod:

Sod is the grass and soil beneath it, held together by roots and rhizomes. Can be harvested into rolls or square slabs (not rolled up)

Turfgrass/turf:

This term refers to the grass on the field pre harvest.

Foliar fertilizer:

Fertilizer given for uptake through the leaves, as opposed to fertilizer given to the soil up through the roots

Liquid fertilizer:

Fertilizer given in a liquid form, as opposed to granular fertilizers.

Plant Marvel:

A type of liquid fertilizer

Fullgjødsel:

A type of granulated fertilizer

Biochemicals:

Biochemicals are biologically derived chemicals, such as biostimulants and humic acids Biostimulants and humic acids are further described in chapter 2.

2 Theory/Literature

2.1 What is sod quality?

As stated in chapter 1.0, quality can be measured in different ways. Color, number of shoots per square meter, root mass, thatch accumulation, number of weeds, the concentration of open soil in the sod, as well as the general impression on the sod, will together say something about the quality of a sod. However there are definitions on turf quality. Turfgrass Producers International (TPI) published a paper where quality is divided into three grades, and use the following definition (TPI, 1995):

A. Premium Grade turfgrass sod shall contain only the species and variety of turfgrass shown on the invoice/sales slip, and contain no weeds or foreign grasses (i.e., no other varieties or species). It may have no visible signs of disease or insect stress. The turfgrass sod shall be neatly mowed and be mature enough that when grasped at one end, it can be picked-up and handled without damage.

B. Standard Grade turfgrass sod may have no visible broadleaf weeds when viewed from a standing position and the turf shall be visibly consistent, with no obvious patches of foreign grasses. In no case may the total amount of foreign grasses or weeds exceed two percent of the total canopy. The turfgrass sod shall be neatly mowed and be mature enough that when grasped at one end it can be picked up and handled without damage.

C. Commercial Grade turfgrass sod shall be any material that fails to meet the Standard Grade specifications.

2.2 Most important turfgrass species for sod production

To produce a high quality sod, the turf has to have good rooting ability as well as good appearance (nice color, high shoot density, low content of soil spots and weeds). Aamlid and Kvalbein (2012) did a validation of turfgrass species for Norwegian green areas. In their research, grass species were ranked from 1-9 with regard to establishment rate, shoot density, leaf fineness (texture), winter strength (resistance to physical and biotic damages), winter color, fertilizer requirements, horizontal growth, wear tolerance, resistance to in-season diseases, and tolerance to low mowing, shade, drought tolerance and salinity (Aamlid and Kvalbein, 2012).

2.2.1 Kentucky bluegrass *(Poa Pratensis L.)*

The most important species in sod production is Kentucky bluegrass (*Poa pratensis* L.). Kentucky bluegrass requires a high amount of nutrients and approximately neutral soil pH. Plants have wide leaves (2-5 mm), few seed stems and many shoots. The species develops underground stems (rhizomes), which forms the sod mat and helps the grass to tolerate physical stress better (Figure 1). These rhizomes will also enable the grass to spread laterally and recover from injuries. Negative aspects of Kentucky bluegrass are slow establishment rates (12-14 days under good conditions), and poor tolerance for low mowing and shade (Molteberg and Aamlid, 2007).

Figure 1: The root system of a Kentucky bluegrass dominated roll of sod. Photo Trygve Aamlid

In most situations, turf for sod production is initiated by sowing Kentucky bluegrass together with red fescue (*Festuca rubra L.)* or/and perennial ryegrass (*Lolium perenne*

L.) in a mixture. This gives more flexibility and ensures that the sod will establish on areas with different growing conditions (Aamlid and Kvalbein, 2012). Kentucky bluegrass has been used on football fields in Norway for many years.

2.2.2 Red fescue *(Festuca rubra L.)*

Red fescue is the second most important species for sod production. Red fescue is divided into three subspecies:

F. rubra ssp. *commutata* – red fescue without rhizomes

F. rubra ssp. *trichophylla* (syn. *F. rubra.* ssp. *litoralis*) – red fescue with short rhizomes

F. rubra ssp. *rubra* – red fescue with long rhizomes

Red fescue is a fine-bladed species with almost as good characteristics concerning winter stress tolerance as Kentucky bluegrass. It tolerates dry conditions and does not have as high nutrient demands as Kentucky bluegrass. Red fescue is less wear tolerant than Kentucky bluegrass, but it has a high tolerance for low mowing, shading and fungus attack. Because of is its high tolerance for low mowing, it can be used on golf greens, often in mixtures with colonial bent grass (*Agrostis capillaris* L.)

2.2.3 Perennial ryegrass (Lolium perenne L.)

Perennial ryegrass (hereafter only referred to as 'ryegrass') is the third most important species for sod production in Norway. Ryegrass has a beautiful shiny-green color. It thrives best on nutrient rich soils with a mowing height of 20-40 mm. One of the key benefits of ryegrass is its rapid development rate. Because of its rapid growth, it is often used on sports fields to develop a high shoot density. It will outcompete weeds and produce a playable surface faster than any other species. The major negative aspect of ryegrass is its low tolerance for hard winters. Therefore, it is usually not recommended as the only species on sports fields in Norway, but it is often over-seeded into other species; e.g. Kentucky bluegrass (Aamlid et al., 2012, Aamlid and Kvalbein, 2012)

2.3 Sod age

The turf sod has to reach certain maturity before being harvested as sod. The grass must have developed complete coverage and desirable density. Lower temperatures and shorter growing seasons mean that we have a longer production period in Norway compared to regions further south in Europe.

More important than turf color and tiller density are the processes going on under the surface. As the turf gets older, it will develop more roots and rhizomes that hold the sod together at harvest.

As already mentioned, the most frequently used seed mixture for sod production in Norway is Kentucky bluegrass and red fescue. More than anything else, it is the Kentucky bluegrass with its underground stems (rhizomes) that binds the sod together and makes it possible to harvest. Red fescue can be used alone as it has a very dense and fibrous root system (Aamlid et al., 2012), but rhizome development is limited to the creeping subspecies *rubra* and *litoralis* and even when those subspecies are used, the sod is much weaker than Kentucky bluegrass sod. Root growth in Kentucky bluegrass is most rapid during spring (Hall, 1993). Hot summers result in stress and declining root growth. Root growth will resume as summer temperatures decrease, but it will not reach the same intensity as during spring (Hall III et al., 1985). It is therefore beneficial to harvest sod in spring (Beasley and Wilkinson, 2008) or early fall. To develop good quality, the grass should be between 14-21 months at harvest, depending on climate and growing conditions (Hall III et al., 1985).

The time from seeding to harvest can be reduced significantly by putting out netting at the same time as the field is seeded. Netting increases shear strength and holds together the rolls of sod, resulting in an earlier harvest, even if the root system has not reached full maturity. Earlier harvest has economic as well as environmental benefits. An earlier harvest means that the farmer will save money on mowing, fertilization, irrigation as well as application of pesticides. Lower inputs of pesticides and fertilizer, together with less use of machinery, are beneficial to the environment (Resietter, 2001). Less-developed turf has some beneficial properties inasmuch as the grass gets older, there will be more thatch resulting in a reduced root development (Hurto et al., 1980). A less-developed and younger root system may well be more vigorous, thus resulting in faster attachment to the underlying soil.

On the other hand, there are also negative aspects resulting from a shorter production period. A less mature turf with a lower concentration of roots in the upper layer usually requires the cutting of a thicker sod. Earlier research on the issue of soil removal, concluded that sod production has benefits because of the turf's ability to hold the soil in place, reducing wind and water erosion significantly (Hesseltine and Skogley, 1978). These researcher concluded that sod production supplied the soil with fertile organic matter and that soil loss from sod production was less than from the production of potatoes, mainly because of less erosion. Later research came to the opposite conclusion that sod production severely depletes fields with good agricultural soils (Millar et al., 2010). According to this report, cylinders taken from fields with a 30-year history of sod production of had a significantly lower thickness of the colian mantle compared with adjacent forested areas. Although good turfgrass management and good harvest techniques, may potentially reduce soil removal, there is always a risk that the harvest of less mature turf after shorter production periods will result in greater soil removal from agricultural fields (Millar et al., 2010).

2.4 Nutrients and fertilizers

The nutrient- and pH status of soils are important parameters for sod production. Fertilizer programs are developed on the basis of soil samples showing the nutrient status in the soil. Application of fertilizers is important to achieve the desired density, color, growth, and general impression of the turf.

The macro- and micronutrients essential for plant growth are listed in Table 1. All of these elements must be present in order for the plant to develop and grow, but it is beyond the scope of this thesis to go into detail for every one of them. Therefore, only mechanisms for nutrient uptake and the most important nutrients in sod production will be described in this chapter.

Table 1: Macro- and micronutrients need needed for plant growth development. (Brady and Weil, 2002b)

Macronutrients: Used in relatively large amounts (>0.1% of dry plant weight)		**Micronutrients: Used in relatively small amounts (<0,1% of dry plant tissue)**
Mostly from air and water	**Mostly from soil solids**	**From soil solids**
Carbon (CO^2)	Nitrogen (NO_3^-, NH_4^+)	Iron (Fe^{2+})
Hydrogen (H_2O)	Phosphorus (H_2PO4^-, HPO_4^{2-})	Manganese (Mn^{2+})
Oxygen (O^2, H_2O)	Potassium (K^+)	Boron (HBO^3)
	Calcium (Ca^{2+})	Zinc (Zn^{2+})
	Magnesium (Mg^{2+})	Copper (Cu^{2+})
	Sulfur (SO_4^{2-})	Chlorine (Cl^-)
		Cobalt (Co^{2+})
		Molybdenum (MoO_4^{2-})
		Nickel (Ni^{2+})

2.4.1 Movement of nutrients from soil to roots and vice versa

For plants to utilize nutrients in soil, the nutrients have to be in contact with plant roots. In most cases the nutrients must be present in the rhizosphere, which is the part of the soil where the microbial population is influenced by the presence of roots (Brady and Weil, 2002a). This can be achieved by root interception or by mass flow or ion diffusion. Nutrients and water are taken up through the finer white roots, rather than through the thicker and older parts of the root. It is therefore important to stimulate plants to develop extensive root systems. An extensive root system will make nutrient uptake easier because, in this situation, roots are in contact with greater quantities of available nutrients in the soil solution (Carrow et al., 2001).

2.4.2 Root nutrient uptake

The main tasks for roots are to hold the grass in place and to ensure nutrient- and water uptake by the plant. Nutrient uptake is selective, meaning that some ions are taken up at the expense of others while some nutrients are taken up in very small concentrations (Repstad, 2005b).

The previous section reviewed how nutrients from the soil solution get into the rhizosphere. In order for plants to utilize nutrients, further transport must occur into the roots and from the roots to the shoot. For nutrients to be taken up by the plant, they first have to enter root cells by crossing the plasma membrane. Transport goes through the symplast to the core of the root, then further to the rest of the plant. There are three fundamental concepts for how nutrients are transported through the membrane: i.e. simple diffusion, facilitated diffusion and active transport. Active transport requires energy (ATP), and is driven by pumps. Differences in charge drive the ions across the membranes. Simple diffusion and facilitated diffusion are passive transport mechanisms and nutrients are transported into the cell without the use of energy. Under facilitated diffusion, the transport is carried out with the help of channel- or carrier proteins across the membrane (Carrow et al., 2001, Repstad, 2005b, Hopkins and Hüner, 2008).

Transport of H^+ back and forth across the membrane is how the cells maintain a membrane potential, meaning the pH status can differ from one side to another of the membrane. Soluble compounds with low molecular weight can move into the cell wall and further to the Casparian strip without crossing a membrane. The cell wall has pores with a diameter of 5 nm, through which solubles such as salts, sugars, amino acids, and simple organic acids can pass. Magnesium, iron, zinc and manganese have to be released from their chelated form in order to be taken up through the cell membrane (Marschner, 1995, Repstad, 2005b). For the roots to take up nutrients, they are dependent on oxygen, carbohydrates and a minimum soil temperature. Uptake of phosphorus is one of the nutrients most dependent on a certain amount of carbohydrates and a minimum temperature.

Plants are able to carry out a luxury uptake of certain nutrients and elements. Potassium (K) is one example, where the plant can take up excess amounts of K, often at the expense of other nutrients. A high amount of ammonium uptake, could lead to decreased uptake of both potassium (K) and magnesium (Mg). This kind of interaction, where an excess uptake of one element will hinder another element, is called antagonistic (Repstad, 2005b). The opposite of antagonistic effect, a synergic effect, occurs when uptake of one element ion will cause an easier uptake of another element.

The concentration H^+ (pH) in the soil is a critical variable in soil chemistry. pH values will determine the solubility of nutrients in the soil solution. Fertilization with ammonium (NH_4^+) will release high amounts of H^+ in the soil solution, resulting in acidification of the soil. A low pH will lead to a decreased uptake of positive ions such as potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}) etc. (Repstad, 2005b)

2.4.3 Foliar nutrient uptake

In terrestrial plants, the majority of nutrient uptake occurs through the roots, as opposed to aquatic plants that utilize leaves to collect nutrients for growth and development. In grasses, the outer wall of the epidermal cells restricts nutrient uptake through leaves. The cuticle and a layer of epicuticular wax cover the outer wall. The main function of cutinized layer within the cuticle is to protect the grass from excessive water loss through respiration and to act as a defense against pests and disease (Marschner, 1995). Solutes with low molecular weight can enter leaves by penetrating the cuticle. The pores of the cuticle are less than 1 nm in diameter with a density corresponding to 10^{10} pores per cm^{-2} of leaf surface. These small pores will restrict larger solutes from entering the leaf through the cuticle. Urea has a diameter of 0.88 nm and is one of the solutes that can penetrate the cuticle. The small pores have a negative charge, attracting cations and repulsing anions. Uptake of NH_4^+ will therefore be faster than uptake of NO_3^- (Marschner, 1995). Nutrient uptake into cells is done with the aid of selective channel proteins or specific carrier proteins in the cell membrane (Repstad, 2005a). Uptake through stomata openings is very restricted, but can occur for toxins in polluted areas.

In the situation where root uptake is limited, uptake through leaves will be important. Even if there are nutrients in the soil solution, they have to be plant-available for plants to utilize them. Under drought, there will be a limited transport of nutrients to the rhizosphere where they can be taken up by the roots. Under these conditions, leaves can supply the grass with nutrients, even though root uptake cannot occur (Repstad, 2005a).

Foliar application of nutrients can be valuable when corrections in the fertilizer programs have to be done, especially for iron (Fe^{2+}) and manganese (Mn^{2+}). This can be very effective under stressful conditions. Foliar application of nitrogen may contribute to less leaching under circumstances where golf greens are exposed to heavy rain, (Carrow et al., 2001).

Important for foliar uptake is that the applied product stays on the leaf surface. Foliar application therefore requires sprayers with the right size nozzles. It is important to follow product instructions. Compared with liquid fertilizers applied for root uptake, foliar application uses a low volume of water. Excess amounts of water can cause nutrients to be washed off the leaf surface, (Carrow et al., 2001).

Another term often used in connection with foliar application is ‘spoon-feeding’. The basics of spoon-feeding are that the manager applies nutrients in small dosages frequently. This ensures better control of the nutrient status of the soil as it prevents nutrient loss through leaching or surface runoff. To facilitate foliar uptake, the amount of water is usually less than 4 l /100 m^2. This will ensure that 95-100% of the applied nutrients will stick to the leaf surface (Repstad, 2005a, Lyons and O´Connor, 2008).

Foliar nutrition has some negative aspects. Nutrients on leafage can cause leaf burn. The ions (salts) will attract water from of the cells, causing cells to desiccate. Another problem with foliar nutrition is that nutrients vary in their degree of mobility in plants. Nutrients, such as sulfur (S), boron (B), manganese (Mn), copper (Cu) and iron (Fe) has a low mobility in plants. Gas exchange can be an additional problem, which prevents nutrients from entering foliage. Urea-based nitrogen can release ammonia to the environment which is potentially an environmental as well as an economic loss if the product is applied incorrectly or under unfavorable conditions (Carrow et al., 2001, Repstad, 2005a, Lyons and O´Connor, 2008)

Foliar nutrition should not be a replacement for solid or fluid fertilizers given to roots. Rather, it should be a supplement in the fertilizer management program, ensuring nutrients for the grasses under stressful circumstances (Carrow et al., 2001, Repstad, 2005a).

2.4.4 Nitrogen (N)

Nitrogen (N) is an essential macronutrient and is the most frequently deficient nutrient in non-legume cropping systems (Havlin et al., 2005). It is also the macronutrient present in greatest quantities in dry leaf tissue. N has a key role in the protein synthesis and is an important constituent in chloroplasts (in the chlorophyll and enzymes). Chlorophyll is important for photosynthesis where energy is absorbed from the sun. Hormones control many responses in the plant. Auxins, cytokinins, and ethylene all contain N in small quantities (Carrow et al., 2001).

Nitrogen is important for:

- Overall turfgrass growth and development
- Turfgrass response to stressful conditions
- Environmental impacts of sod production

Nitrogen is taken up in plants as ammonium (NH_4^+) or as nitrate (NO_3^-). Plants usually take up NO_3^- in greater amounts than NH_4^+. Ammonium has to be incorporated into organic compounds in the roots whereas nitrate is readily mobile in the xylem and can also be stored in the vacuoles of roots, shoots, and storage organs (Marschner, 1995, Havlin et al., 2005).

Rapid uptake of NO_3^- will increase the pH in the rhizosphere as it is accompanied by uptake of H^+ to maintain neutrality of root cells. The grasses need to metabolize NO_3^- to NH_4^+ and further into amino acids and proteins. As stated earlier, metabolism of NO_3^- is an energy-demanding process where 2 NADH molecules are used to reduce NO_3^- to NH_4^+ prior to protein synthesis. NH_4^+ is the preferred N source, because of its passive uptake (Havlin et al., 2005).

It is beneficial with a neutral pH in order to get an efficient uptake of NH_4^+. The uptake of this cation is suppressed in acid soils. Furthermore, uptake of NH_4^+ will cation uptake of ions such as Ca^{2+}, Mg^{2+} and K^+ whereas anionic nutrients will have a more efficient uptake ($H_2PO_4^-$, SO_4^{2-} and Cl^-). When NH_4^+ is taken up in the roots, H^+ is secreted to maintain a neutral charge within the roots. If NH_4^+ is applied over a longer period of time, the soil will become more acid, which can make nutrients unavailable for uptake, unless the soil is limed. High amounts of NH_4^+ can retard growth, compared to NO_3^-. It could be beneficial to apply both NH_4^+ and NO_3^-, as opposed to separate applications (Havlin et al., 2005).

N has a strong impact of several processes in grasses. Responses to N include: (1) color, (2) shoot growth, (3) shoot density, (4) root growth, (5) rhizome and stolon growth, (6) carbohydrate reserves, (7) high temperature stress, (8) cold tolerance, (8) drought resistance, (9) compaction and wear tolerance, (10) thatch accumulation, and (11) recuperative potential. All of these responses are dependent on the rate of N applied. Very high rates of N have proven beneficial to turfgrass color, shoot growth and shoot density. By contrast, rhizome/stolon growth, drought resistance, cold tolerance, compaction/wear tolerance and recuperative potential are usually stimulated by medium-to-high concentrations of N. Responses which benefit from low-to-medium rates of N are root growth and carbohydrate storage (Carrow et al., 2001).

At higher N rates, there is an increase in chlorophyll, causing the grass to respond with a darker green color. Shoot growth and shoot density show some of the same pattern. As cell growth depend on amino acids and proteins, more N will lead to more frequent mowing and larger cells with thinner cell walls.. When additional N is added, there is often a linear relationship between N applied and tillering (Carrow et al., 2001).

Carbohydrate reserves are important for grass survival during dormant periods, and for stress tolerance and recovery. Carbohydrates are stored in the roots. When N is applied in excessive amounts, the plants will stop storing carbohydrates and rather use their energy to produce shoots and leaves. Excess amounts of N could therefore lead to a depletion of carbohydrate reserves in the crowns, rhizomes and roots, thus making the plant more vulnerable to stress (Hall, 1993). Root growth as well as rhizome- and stolon growth is closely correlated with carbohydrate reserves. In order for the grass to develop an extensive root system, it depends on a continuous supply of carbohydrates from shoots to roots. Under low N rates, sugars produced in leaves are transported to the roots. Even if the color of the grass is light green, root development may be good under such circumstances. Rhizomes are also negatively affected by excess supply of nitrogen, while the development of stolons is less susceptible to high N applications. Stoloniferous grasses need N in order to spread. (Carrow et al., 2001).

It is important that a turfgrass manager has a good understanding of nitrogen because of its impact on grass, soil, environment and economy (Carrow et al., 2001).

2.4.5 Phosphorus (P)

Phosphorus is one of the primary nutrients (together with N and K), which are required to develop a healthy turf. Many Norwegian soils have high amounts of plant-available phosphorus (P-AL) because they have been over-fertilized for many years. Crops show no negative effects of very high P-AL values, but P is an environmental problem as leaching and surface runoff cause severe pollution of rivers and lakes. Phosphorus is taken up inorganically as $H_2PO_4^-$ or as HPO_4^{2-}, and it is very mobile in the plant (Marschner, 1995, Carrow et al., 2001, Hopkins and Hüner, 2008).

Most importantly, it is a component of both adenosine diphosphate (ADP) and adenosine triphosphate (ATP) that are essential for the transport and storage of energy in the plant. Because of P importance in relation to energy metabolism, P deficiency will result in restricted growth and development. P is also a component of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), which are important for protein production. Adequate supplies of P have been associated with increased root growth and with shorter time for ripening and crop maturity. (Havlin et al., 2005).

2.4.6 Potassium (K)

K is very important for turfgrasses. It doesn’t influence growth and development to such an extent as N and P but has a large influence on stress caused by drought, cold temperatures, physical wear and salinity. K is very susceptible to leaching, especially on sandy soils. It is taken up actively as K^+ and is very mobile although regulated by K-channels in the plasma. It is not unusual that plants have a luxury uptake of K. Ryegrasses are able to take up great amounts of K, and this uptake can lead to a lower uptake of other cationic elements (Carrow et al., 2001).

Potassium is required for activation of several enzymes. It is also important in osmoregulation, which involves; (1) water transport in the xylem influencing total water uptake, (2) maintenance of cell turgor pressure, (3) cell extension, and (4) stomatal opening, which, in turn, controls respiration, transpirational cooling, and CO_2 uptake. Under K deficiency, grasses become exposed to drought stress, which can be severe under high summer temperatures. Stomatal control will then decrease, resulting in a higher evapotranspiration when stomatal openings are left open. As water use increases, grasses can be exposed to wilting, resulting from loss of turgor pressure.

K supplementation results in a more extensive root system of creeping bentgrass (*Agrostis stolonifera* L.) on sandy soils in. Such soils are exposed for drought and a more fibrous network of roots will therefore lead to improved water (and nutrient) uptake. When grasses are dormant during winter, K will also help to maintain cell moisture during prolonged cold period. (Carrow et al., 2001)

2.4.7 Iron (Fe) and other micronutrients

Micronutrients occur in plants and in soil in lower concentration (Marschner, 1995, Havlin et al., 2005). However, the present of these elements are just as important, as the present of macronutrients. Micronutrients, vital for plant growth and development are listed in table 1. The concentration needed for the plants are often present in the soil. However, deficiencies can occur on turf seeded on sandy soils with low organic content (Landschoot, 2003).

Micronutrients can be present in the soil, but unavailable for plant uptake. Iron copper, zinc and manganese often are often bound to other compounds. To correct this problem, the nutrients can be applied as chelates. The chelating agent binds to the nutrient, and it remains in solution and is released to the root surface. Nutrients applied as chelates are often more expensive, but has proven to be a superior source of micronutrients. However, lower rates can be used because of higher availability, reducing the risk of plant injury (Landschoot, 2003).

Iron can be taken up as Fe^{2+} or as Fe^{3+} and is important for enzymes and proteins in respiration, chlorophyll synthesis and nitrogen metabolism (Carrow et al., 2001, Landschoot, 2003). In turfgrass production, iron is often applied to enhance better grass color. Even if the content of iron is sufficient in the tissue, supplements of iron and a reduction of nitrogen, has proven to stimulate the grass to a darker color, without the negative effects of frequent nitrogen applications. Iron can be taken up through roots or leafs. The most common source is inorganic iron salts, often with ammonium and sulfate, or organic iron and chelates (stated above). A research on foliar application of iron, looked at the color response on Kentucky bluegrass. The research concluded that iron from chelates was more effective than sulfate sources. The research also indicated that the use of iron to improve color, and reduce nitrogen was feasible (Fermanian et al., 1984).

2.4.8 Solid versus fluid applications

Fertilizers can be applied as solids or fluids (liquids). The choice of solid or fluid application is determined by economics, transport, handling, storage and equipment. Solid fertilizers include granulated products, either bagged or bulk. Powders prepared specifically for application with water are also under this category. The use of liquid fertilizers in turfgrass production has increased tremendously over the last years. There are several reasons for this: Storage in tanks, less handling of bags, convenience of obtaining various nutrient ratios when mixing materials in in spray tanks, and the possibility of tank mixtures of pesticides and fertilizers. The capability of the turfgrass manager to spread the fertilizer uniformly is also a key factor when choosing application method (Carrow et al., 2001).

The response to fertilizer application, either fluid or solid, is the same when the nutrient sources are essentially the same. Granular fertilizer or fluid application with excess amounts of water will prevent fertilizers to retain on foliage which will result in less burning of the foliage and fertilizer removal through clippings (Carrow et al., 2001).

2.5 Biochemicals

Biochemicals are biologically derived chemicals, such as biostimulants, humates, humic acids and composts (Carrow et al., 2001). This chapter will only review humic substances and biostimulants because of their relevance to the thesis.

2.5.1 Humic substances

Humic substances are commonly split into humic acids, fulvic acids and humins. Varshovi (1996) and Carrow et al. (2001) use the following definitions:

Humic acids are humic substances not soluble (i.e., precipitates) in water under very acid ($pH<2$) conditions, but can be extracted from soil with dilute alkali or other extractants. Fulvic acids are fractions of humic substances that are soluble in water under all pH conditions. Humin is not soluble in water at any pH. (Varshovi, 1996, Carrow et al., 2001)

Commercially available humic substances arrive from different kind of sources. Any organic material can be composted and be a source of humic substance. However, natural deposits, composted sewage sludge and seaplants are commercially used on a big scale (Carrow et al., 2001). Humic substances are applied as solids or liquids.

Liquids usually contain both humic- and fluvic acids, where fluvic acid is often the more active component. In commercially sold products, the term 'humic acids' often includes both components, the total content varying from 1 to 12% of dry weight. Usually, the products also contain various amounts of plant nutrients. However, because the products are given in low amounts per unit area, the amounts of nutrients applied is usually very low except when additional fertilizers are added (Carrow et al., 2001).

Humic substances often have beneficial effects on turfgrasses. Following is a list of potential of some of the responses (Chen and Solovitch, 1987, Varshovi, 1996, Liu and Cooper, 1999, Carrow et al., 2001):

- Stimulation of microbial populations, (if the C:N ratio is sufficiently low)
- Better water holding capacity as well as better soil structure, as a result of more microbial activity
- Enhanced soil nutrient content, as well as increase the solubilization of micro- and macro nutrients (P, Ca, K, Fe, Mn, Zn)
- Increased Cation Exchange Capacity (CEC), resulting in lower toxification of metal ions. Additionally, chelating of microelements leads to a better plant uptake of these elements. Fulvic acid is most active as a chelating agent.

According to Carrow et al. (2001), a desirable amount of humic plus fulvic acids in a turfgrass root zone is approximately 75 kg/ha^{-1}. Many soils already contain these amounts but soils with very low contents of organic matter could receive beneficial effects.

2.5.2 Biostimulants

Not to be confused with humic substances, biostimulants have hormonal properties when applied to plants and can be natural plant extracts such as *(Ascophyllum Nodosum)* (Carrow et al., 2001). There are five groups of natural hormones (auxins (IAA), gibberellins (GA), cytokinins, ethylene, and abscisic acid (ABA)), biostimulants can therefore stimulate growth but the same materials may also cause an inhibitory response if applied at high concentrations or in a manner that cause imbalance with other hormones (Carrow et al., 2001). Like natural hormones, biostimulants act at very low concentrations and not like nutrients where higher rates produce greater responses than lower rates in most cases.

Since biostimulants have hormonal properties, it is important to understand the function of the five groups of natural plant hormones. The five groups influence different responses, such as dormancy, cell elongation, cell division, root initiation, flowering, senescence and many other processes. Different hormones trigger several responses, some beneficial and some negative responses in relation to growth and development of a healthy turf (Carrow et al., 2001).

Sod production is a very intensive enterprise. Apart from weather conditions such as cold, heat, drought and heavy rainfall, the turf is exposed to stress when heavy machinery such as big mowers, grass collectors and heavy rollers are used on a weekly basis. Intense traffic on turf will sooner or later lead to compaction of the upper soil layer. This compaction can be prevented by the use of lighter machinery even though producers need efficient machinery to be able to run an efficient business. The stressful conditions can impact the hormone production and balance in plants. That is why an application of hormones can prove to be beneficial for grass growth.

Cytokinins are the group of plant hormones most commonly used as biostimulants in in turfgrass management. Cytokinins are produced in plant roots, especially in the root tips, and transported to the shoots. If roots are absent, e.g. under stresses such as drought, dieback, O_2 deficiency, high soil strength or metal toxicity, then biostimulants can replace the natural cytokinins, and increase the hormonal level up to a beneficial concentration.

Earlier research has reported that cytokinins inhibit leaf senescence and chlorophyll loss. Cytokinin applied to shoot tips has also been shown to increase tillering if roots have been suppressed or missing. Under these circumstances, cytokinins can also help with the regrowth of roots

2.6 Washed sod

A problem with the use of sod is that the soil attached to the turf may have a different particle size distribution than the soil at the installation site. Soil with a higher content of silt and clay has a higher concentration of smaller pores, which can hold more water. For a silt or clay to drain water, you need suction through the soil profile down to the drainage. Sports fields often have sandy soils to ensure a playable surface under wet conditions. Sandy soils will also give the manager better control of the nutrient status of the soil. On such soils and top layer, containing silt or clay will result in problems with root penetration into deeper layers. A fertile soil with a smaller particle size distribution will contain more water and nutrients, and prevent the roots to grow downwards to an area with a lower content of water and nutrients (Hillel, 2004).

The best way to avoid these problems is to grow the turf on an equal soil to where the sod is going to be installed. To facilitate this, a contract may be signed between the supplier/producer of the turf and the owner of the sports field. Alternatively, the turf can be grown on regular soil and then washed before installation. In short, the washing process will involve machinery where the sod rolls are placed on a conveyor belt. Nozzles with high-pressure water will then wash off the soil. Earlier research has shown that washed sod produces a significantly more roots than unwashed turf (Casimaty et al., 1993, Table 2).

Table 2: Maximum root depth and root dry weight at different times from installation on a sandy soil of washed sod and unwashed sod produced on two soils at different weeks (Casimaty et al. 2003).

Treatment	**Maximum root depth, cm**							**Root dry weight m^2**	
Weeks after	14	21	28	35	42	49	56	21	42
Washed sod	40	61	79	98	114	122	112	22	39
Unwashed sod produced on a sandy loam soil	44	50	63	91	119	117	109	8	26
Unwashed sod produced on a Clay loam soil	29	38	56	74	83	89	79	6	17

3 Materials and methods

3.1 Location of the research

The research was initiated in an already seeded sod field in Rygge, which is located in Østfold County in the southeastern part of Norway (Figure 2).

3.2 Weather data

The test site is situated in the H2/H3 climate zone, which is considered to be a mild Norwegian climate (Scale from 1-8)

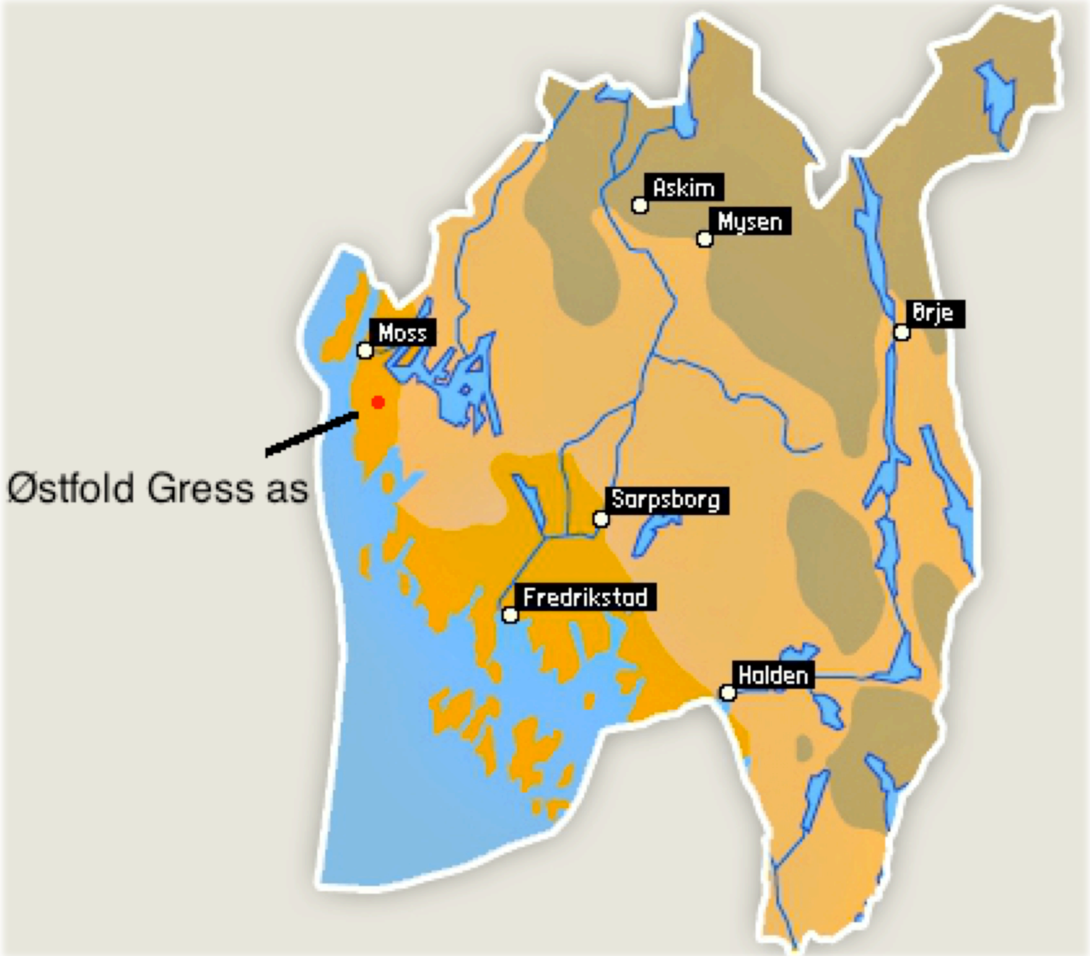


Figure 2: Climate map of Østfold. Rygge is located in the northwestern part of the county map: http://www.bogront.no/klimasonekart

Table 3: Average monthly temperature and precipitation from May 2010 to November 2011 compared with 30 year normal values (1961-90) at Rygge weather station.

Month	Average temp (°C)	Normal temp (°C)	Precipitation (mm)	Normal Precipitation (mm)
May.10	10.3	10.3	55	57
June.10	14.4	14.7	69	63
July.10	17.3	15.9	70	73
August.10	15.9	14.9	143	88
September.10	11.2	10.8	89	94
October.10	6.1	6.8	78	106
November.10	-1.9	1.2	54	87
December.10	-10.3	-2.5	20	63
January.11	-3.8	-4.1	42	58
February.11	-4.7	-4.2	49	43
March.11	0.7	-0.4	16	54
April.11	8.5	4.2	55	43
May.11	10.9	10.3	67	57
June.11	15.4	14.7	79	63
July.11	17.5	15.9	83	73
August.11	15.8	14.9	107	88
September.11	13.2	10.8	200	94
October.11	8.8	6.8	68	106
November.11	4.9	1.2	50	87
Sum			1393,4	1397
Average	7.9	7.5		

The growing season in 2010 had approximately normal summer temperatures but temperatures during late November and during December were lower than normal. The overall temperature for the growing season May-October was 0.3 C higher than the 30 year normal. Because the farm did not have a functioning irrigation system, the grass was not irrigated during the growing season in 2010. Water was provided through precipitation.

The growing season in 2011 started with record-high temperatures in April. The rest of the growing season was also mostly warmer and with much more precipitation compared to previous season. Irrigation was therefore not necessary. Of special interest is the fact that September and October had higher-than-normal temperatures, which are conducive to better grow-in of sod after installation.

3.3 Soil analyses

3.3.1 Chemical analysis

Soil samples were taken in May 2010 and analyzed for pH in distilled water and nutrient content using AL extraction (Analycen soil lab, Moss, Norway). The analysis showed a pH 5.7, and P-AL, K-AL, Mg-AL, Ca-AL and Na-AL values corresponding to 9, 17, 7, 110 and < 5 mg (100 g dry soil)$^{-1}$, respectively.

3.3.2 Particle size distribution and loss on ignition

Analysis of the particle size distribution and loss on ignition of the soil at the production (two samples) and installation sites was done at Norwegian University of Life Sciences (UMB) in January 2012 (Table 4). The analysis was done according to the standard method used at UMB (Øien and Krogstad, 1989)

Table 4: Particle size distribution and organic matter in percentage of the soil.

Soil	Fineness	Fraction	A	B	Install
Sand	**Coarse**	0,6-2 mm	4	3	18
	Middle	0,2-0,6 mm	19	9	32
	Fine	0,06-0,2 mm	27	36	27
Silt	**Coarse**	0,02-0,06 mm	22	18	9
	Middle	0,006-0,02 mm	6	8	3
	Fine	0,002-0,006 mm	2	9	2
Clay		<0,002 mm	20	17	9
Organic Matter (loss on ignition)			5.5	5.3	5.4

The Soil at the production site was classified as loam, whereas the soil at the installation site was categorized as a sandy loam (Hillel, 2004). The organic matter content was very similar at both sites. The World reference base of “Skog og Landskap” classified the production site as a Mollic Gleysol. The installation site was classified as a Luvic Stagnosol (Skog og Landskap, 2012)

3.4 Experimental plan and implementation

The trial was laid out according to three-replicate split-split plot experimental plan with the following experimental factors:

Factor 1: Sod age (main plots)

A: 16 months old sod: Seeded 1 May 2010, harvested 16 September 2011

B: 12 months old sod: Seeded 5 September 2010, harvested 16 September 2011

Factor 2: Fertilizers

1: Conventional granulated fertilizer: Yara 12-4-18 or 18-3-15 (every 3 weeks)

2: Liquid fertilizer: Plant Marvel (every week): 15-5-30, 13-3-13, 28-8-18

Factor 3: Biochemicals (biostimulants and humic acids) during the sod production phase

3: As 1 + Biochemicals

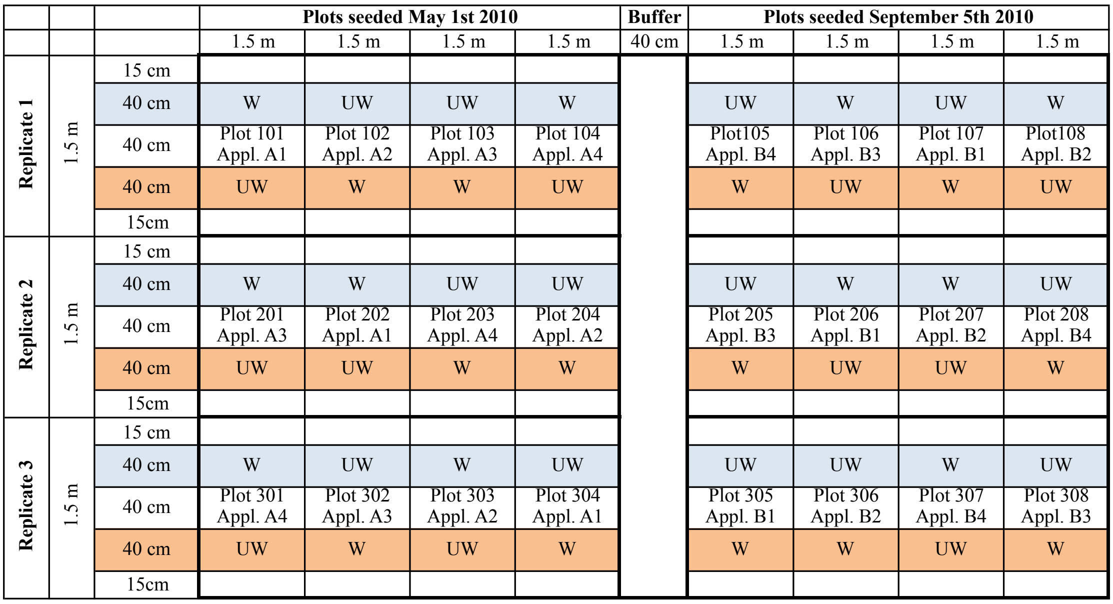
4: As 2 + Biochemicals

Factor 4: Sod washing after harvest, before installation (subplots)

W: Washed sod

UW: Unwashed sod

The area of the three-replicate split-plot trial was 12.40 m x 4.5 m = 55.80 m2, including a central 40 cm border area (figure 3). The area of each main plot was 1.5 m x 6.0 m = 9 m^2, and of each subplot 2,25 m^2 (1,5 m x 1,5 m). Sub-subplots were 1.50 m x 0.40 m = 0.60 m2, plot width being determined by the width of the sod harvester. For practical reasons, two main plots in each block could not be randomly distributed, but had to be located with sod seeded on 1 May and 5 September on the eastern and western side of the experiment, respectively. Subplots receiving various combinations of fertilizers and biochemicals acids were always randomly distributed within each main plot, and sub-subplots with sod to be installed as washed or unwashed sod were always randomly distributed within each subplot.



			Plots seeded May 1st 2010				Buffer	Plots seeded September 5th 2010			
			1.5 m	1.5 m	1.5 m	1.5 m	40 cm	1.5 m	1.5 m	1.5 m	1.5 m
Replicate 1	1.5 m	15 cm									
		40 cm	W	UW	UW	W		UW	W	UW	W
		40 cm	Plot 101 Appl. A1	Plot 102 Appl. A2	Plot 103 Appl. A3	Plot 104 Appl. A4		Plot105 Appl. B4	Plot 106 Appl. B3	Plot 107 Appl. B1	Plot108 Appl. B2
		40 cm	UW	W	W	UW		W	UW	W	UW
		15cm									
Replicate 2	1.5 m	15 cm									
		40 cm	W	W	UW	UW		UW	W	W	UW
		40 cm	Plot 201 Appl. A3	Plot 202 Appl. A1	Plot 203 Appl. A4	Plot 204 Appl. A2		Plot 205 Appl. B3	Plot 206 Appl. B1	Plot 207 Appl. B2	Plot 208 Appl. B4
		40 cm	UW	UW	W	W		W	UW	UW	W
		15cm									
Replicate 3	1.5 m	15 cm									
		40 cm	W	UW	W	UW		UW	UW	W	UW
		40 cm	Plot 301 Appl. A4	Plot 302 Appl. A3	Plot 303 Appl. A2	Plot 304 Appl. A1		Plot 305 Appl. B1	Plot 306 Appl. B2	Plot 307 Appl. B4	Plot 308 Appl. B3
		40 cm	UW	W	UW	W		W	W	UW	W
		15cm									

Figure 3: An illustrative overview of the three replicate split-split plot with randomized subplots and sub-subplots

Figure 4: Experimental field after seeding in May 2011. Photo: Ole Christian Trandem

3.4.1 Factor 1 - Sod age / seeding time

The research focused on sod age at harvest, which meant that the grass had to be seeded at two different dates. The older sod was seeded along with the surrounding field on 1 May 2010 using a tractor mounted “Väderstad Rapid 300”. (Figure 5) In preparation for younger sod to be seeded in fall, 50 m^2 was killed with glyphosate on

August 20th, roto tilled and seeded on 5 September 2010, using the same mixture as for the older turf (60% *Poa pratensis*, 30 % *Festuca rubra* and 10% *Lolium perenne*), but with a Scotts SS2 drop seeder (Figure 6). The seedbed was compressed with a roller after seeding.

Figure 5: Väderstad Rapid tractor mounted seeder (Used 1 May). Photo: http://home.no/ferstad/album.html

Figure 6: Scotts SS2 drop seeder (used 5 September). Photo: Ole Christian Trandem

The density of seeds sown on both sowing dates was 150 kg per ha. The following list is the percentage of each cultivar of the different species in the seed mixture:

- 10% Perennial ryegrass (Lolium perenne) ´Greenfair´
- 25% Kentucky bluegrass (Poa pratensis) ´Conni´
- 35% Kentucky bluegrass (Poa pratensis) ´Limousine´
- 10% Chewings fescue (Festuca rubra ssp. commutata) ´Greensleves
- 20% Slender creeping red fescue (Festuca rubra ssp. trichophylla) ´Cezanne´

3.4.2 Factor 2 - Fertilizer

The four different fertilizing regimes were carried out during the growing season of 2011. Throughout the season, conventional granular fertilizer (Yara 18-3-15) was applied evenly by hand in treatments 1 and 3, every 3 weeks. Liquid fertilizers (Plant Marvel 15-3-30, 13-2-13 and 28-8-18) were applied evenly by a hand held pump spray can every week (figure 7). Biostimulants and humic acids were applied every 4 weeks.

Figure 7: Application of liquid fertilizers and biochemicals was done using a pump spray can. Photo: detailersclub.no

Figure 8: Application of granulated fertilizers was done by hand. Photo: http://www.globalnet-industries.com/products/

The total amount of N supplied on the plots was constant, for all plots. The amount of N given to the plots was 20 kg for the younger sod (seeded September 2010), and 13 kg for the older sod (seeded May 2010). The Biochemicals had no nitrogen content. Nutrient content are given in (Table 5). Detailed plans are in Appendix 1. Fertilizers were applied up until sod harvest. No fertilizer was added after the sod was installed. We wanted to see the effect of the fertilizer added pre harvest, on turf characteristics measured pre and post harvest. Micronutrients added in Plant Marvel are chelated, meaning the micronutrients are more easily available for plant uptake.

Table 5: Nutrient volume weights of different fertilizers and Biochemicals (biostimulant/humic acid) products

Fertilizer	Yara		Plant Marvel			Biochemicals	
	12-4-18	**18-3-15**	**15-5-30**	**13-3-13**	**28-8-18**	**Astron**	**PK-Fight**
Nitrogen (N)	11.8	17.6	15	13	28	0	0
(NO_3^-)-N	5.2	8.3	12.2	12.26	5.4	0	0
(NH_4^+)-N	6.6	9.3	2.8	0.74	2.1	0	0
(CON_2H_4)-N	0	0	0	0	20.5	0	0
Phosphorus (P)	4	2.6	2.2	0.7	3.5	0	9.6
Potassium (K)	17.6	14.6	25	10.8	15	0	23.2
Calcium (Ca)	2	1.3	0	0.03	0	3	0
Magnesium (Mg)	1.6	1.5	1.26	3	0	0.75	0
Sulfur (S)	9.5	3.8	0	0	0	0	0
Iron (Fe)	0	0	0.1	0.05	0.1	3	0
Boron (B)	0.03	0.02	0.02	0.0014	0.02	0.2	0
Chlorine (Cl)	0	10.6	0	0		0	0
Manganese (Mn)	0.3	0	0.05	0.028	0.05	0	0
Sink (Zn)	0.03	0	0.83	0.028	0.05	0.5	0
Copper (Cu)	0	0	0.05	0.028	0.05	0.5	0
Molybdenum (Mo)	0	0	0.0005	0.0075	0.0009	0	0

Factor 3 – Biochemicals

Astron is a biostimulant product. It is derived from calcium gluconate, magnesium sulfate, boric acid, copper sulfate, ferrous sulfate and zinc sulfate. It also contains brown algae (*Ascophyllum nodosum*). Extracts from *Ascophyllum nodosum* have proven to induce amylase activity in barley deficient of gibberellins (GA) (Rayorath et al., 2008). The label states that the product will enhance root growth, stimulate cell division and improve stress tolerance and stress recovery. Recommended dosage: 5-10 L ha^{-1} (Floratine, 2012a, Floratine Norge, 2012a).

PK Fight is a potassium phosphite product and is categorized as a foliar supplement for turf. The product contains organic acids, phosphorus and potassium. The label states that the product will increase stress tolerance, root growth and plant health. Recommended dosage: 5-20 L ha^{-1} (Floratine, 2012b, Floratine Norge, 2012b).

In this project, Astron and PK Fight were applied every four weeks in a tank mixture dilutes to an application volume of 10 L ha^{-1}

3.4.3 Factor 4 - Sod Washing after harvest, before installation

At harvest, the subplots were split in two sub-subplots. One strip of sod from each plot went through a washing process. Using a high-pressure washer, the soil was washed out of the turf, leaving behind only the root and rhizome system. Washed and unwashed sod, were installed on a prepared field according to the same split-split-plot experimental layout as they had been harvested.

Figure 9: Washed and unwashed turf after installation. The rolls that were washed were picked randomly within each subplot. There was no soil attached to the washed sod rolls, whereas the unwashed sod had soil attached. Photo Trygve Aamlid

Figure 10: An overview of the experiment after installation. Photo Trygve Aamlid

3.5 Daily maintenance and machinery used during the production phase

3.5.1 Mowing

Plots were mowed two-three times a week from May until October in 2010 and 2011 with a Kesmac cylinder mower at Mowing height was 3.5 cm. Residual grass clippings were removed by a grass collector when necessary (after longer periods of rain e.g.). The mower is seven meters wide with eleven cylinder mower heads connected to one tractor mounted frame (Figure 11).

Figure 11: Kesmac 11 gang cylinder mower. photo: http://www.vanmac.nl

3.5.2 Pesticides

The field was sprayed with Glyphosate (Roundup 3000ml/ha) 19 April 2010, prior to seeding. The plots seeded on 1 May 2010 were sprayed with herbicides during the season of 2010 with Hussar 24 June 2010 (50ml/ha) and 21 July 2010 (50ml/ha). The younger grass (seeded 5 September) was not sprayed.

3.5.3 Harvesting

The sod was harvested using a Ryan 40 cm heavy-duty sod cutter (Figure 12). The harvester had a cutting blade of 40 cm width an adjustable depth controller. The grass was harvested at an approximately 1,5 – 1,7 cm depth (Figure 14) and then rolled up with a labeling pin inside the roll for identification (figure 13).

Figure 12: Ryan 40 cm sod harvester. Photo: http://www.ryanturf.com

Figure 13: Rolls of sod after harvesting the research area Photo: Ole Christian Trandem

Figure 14: The thickness of the rolls was approximately 1.5-1.7 cm. Photo: Ole Christian Trandem

3.6 Collection of data

3.6.1 Visual data collection until sod harvest

Visual assessments were performed every third week at the same time as when the granular fertilizer was applied. Every plot was photographed to document the development.

General impression

General impression is the overall appearance on the plot. The grass species distribution (uniformity), color, concentration of weeds and dead spots all influenced the general impression. The plots were given a grade from 1-9 (9 is the best) General impression was not implemented into the visual data collection, resulting in lack of data on this parameter. Figure 15 shows a plot at visual assessment.

Color

Color was the color of the seeded grasses. Annual bluegrass had a lighter color, but was not a seeded species and was therefore excluded from the color judgment of the plot. Color was assessed on a scale from 1 to 9 (9 is the darkest)

Grass coverage percentage

The percentage of the plot covered by seeded grass is estimated. Grass species not seeded such as Annual bluegrass was categorized as weeds and were therefore not included in the grass cover estimate.

Estimated weed percentage

The area of not-seeded grass and other types of weeds were given as a percentage of the whole plot.

Estimated dead spot or bare soil percentage

The areas of dead spots or bare soil were estimated and expressed as a percentage of the whole plot. Grass cover percentage, estimated weed percentage and estimated dead spot percentage should add up to 100%

Figure 15: Picture taken of plot 104, 12.09.11. This plot received the following grades: General impression: 7, color: 6, grass coverage 100%. Photo: Ole Christian Trandem

3.6.2 Shear strength measurement

Shear strength (rotational traction) was measured of the turf before rupture. As opposed to a soil shear strength, which is forced into the ground, the shear strength apparatus we used, measured the strength of the turf above ground. The apparatus was made from a British design (Canway and Bell, 1986). A disc, 15 cm diameter and with six football studs to simulate a soccer shoe, and loaded to a total weight of 46 kg including a custom-made two-armed torque wrench with a gauge was dropped on the turf from a height of 40 cm When twisted the grass will withstand the forces until it ruptured. Right before rupture the maximal torque was registered. These measurements were done in each subplot three times. The first measurement was done during the growing season, the second at harvest, and third after rooting of the turf post installation.

Figure 16: Studs on the bottom of the apparatus. Photo: Trygve Aamlid

Figure 17: The apparatus was dropped from 10cm at each plot. Photo: Trygve Aamlid

3.6.3 Root analysis

Roots were washed from one cylinder sample (56 mm in diameter) from each subplot just before sod harvest. Root depth was measured as length of intact soil core. After this measurement was done, the core was split into depths 0-5 cm, 5-10 cm and below 10 cm before washing. After washing, roots were dried at 60°C for 48 h before weighing. Separation of soil/sand from the top 0-5 cm layer on 16 September was very difficult; hence, weights may be somewhat overestimated and most emphasis should be put on relative differences.

Figure 18: Soil cylinders were taken from the center of each plot. Photo: Trygve Aamlid

Figure 19: Soil cylinders extracted out of the apparatus. Photo: Trygve Aamlid

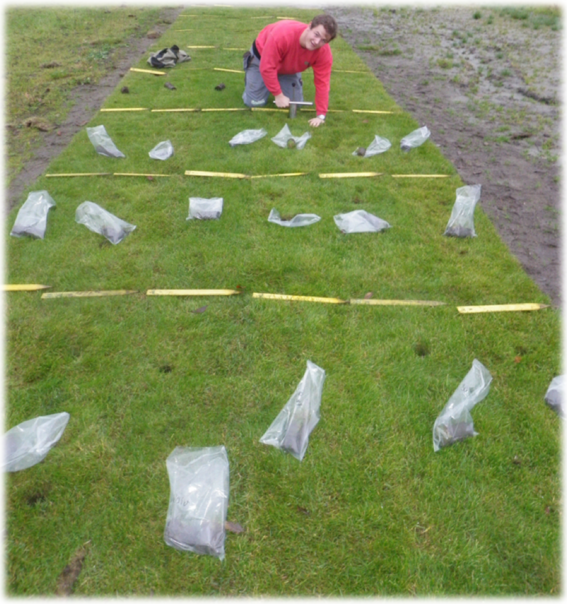


Figure 20: Cylinders were placed in bags. Photo: Trygve Aamlid

Figure 21: Two cylinders were taken from each plot, one cylinder for botanical composition and shoot density, and the other cylinder for root development analysis. Photo: Ole Christian Trandem

3.6.4 Botanic composition and shoot density

At sod harvest on 16 September, another cylinder, also 56 mm in diameter, was taken out from each plot to examine the density of shoots and the frequency of the species red fescue, perennial ryegrass, Kentucky bluegrass and annual bluegrass within each subplot the analysis was carried out at Bioforsk Landvik

3.6.5 Visual data collection post installation

After the sod had been installed, the grass was visually inspected for general impression, color and root development.

3.6.6 Root development

Root development was assessed visually by the appearance of roots and how good the sod was attached to the underlying soil. Rooting was given a score from 1 to 9 (9 is the best). Using the same auger as before sod harvest, we also took cylinder samples from each sub-subplot for washing of roots that had grown into the underlying soil (figure 18, 19).

3.7 Statistical data

The experimental data were analyzed according to the split-spilt model using the PROC ANOVA procedure of SAS software package, version 9.2 (SAS Institute, Cary, NC, USA). Throughout this thesis, the term ‘significant’ always refers to the 0.05 probability level. Effects within the 0.05-0.20 probability range are reported as ‘tendencies’.

4 Results

4.1 Results obtained during production and sod harvest

4.1.1 Turf coverage and visual characters

Main effects and significance levels for interactions are presented in Table 6, while the most important interactions are shown in Figures 22 and 23.

Table 6: Main effects and significance levels of sod age, fertilizers and biochemicals on turf coverage (seeded species, % of plot area), weed content (% of plot area), general impression (1-9, 9 is highest quality) and turf color (1-9, 9 is darkest turf). Significance levels for the two and three factor interactions have also been indicated.

Factors	**Mean values of growing season 2011 until sod harvest**			
Sod age / sowing time	**Turf cover %**	**Weed %**	**General imp (1-9)**	**Color (1-9)**
Mature (May 2010)	99.7	0.6	7.7	5.9
Young (Sept 2010)	49.8	12.9	3.8	6.6
***P*-value**	0.0006	0.004	0.002	0.02
Fertilizer				
Fullgjødsel	75.4	6.3	5.7	6.2
Plant marvel	74.1	7.2	5.8	6.3
***P*-value**	0.01	>0.15	>0.15	>0.15
Biochemicals				
Without	74.7	7.2	5.6	6.2
With	74.8	6.3	5.9	6.3
***P*-value**	>0.15	>0.15	>0.15	0.05
Interactions (*P*-values)				
Sod age x fertilizer	0.02	>0.15	>0.15	0.03
Sod age x biochemicals	>0.15	>0.15	>0.15	0.02
Fertilizer x biochemicals	>0.15	>0.15	>0.15	>0.15
Sod age x fertilizer x biochemicals	>0.15	>0.15	>0.15	0.05

The turf sown in May 2010 had 100% coverage at the start of assessments in May 2011. The young turf (sown in September) had very little coverage at the start of assessments but improved significantly to more than 90% coverage by the end of the season (Figure 22). However, the average grass cover percentage was only 49.8% (Table 6).

Less coverage of seeded grasses resulted in more weeds and lower general impression in the younger turf (Table 6). The turf seeded in May 2010 was dominated by red fescue. Kentucky bluegrass dominated the turf seeded in September 2010. Kentucky bluegrass has a dark color, resulting in a significantly higher average color grading of the younger turf (Table 6).

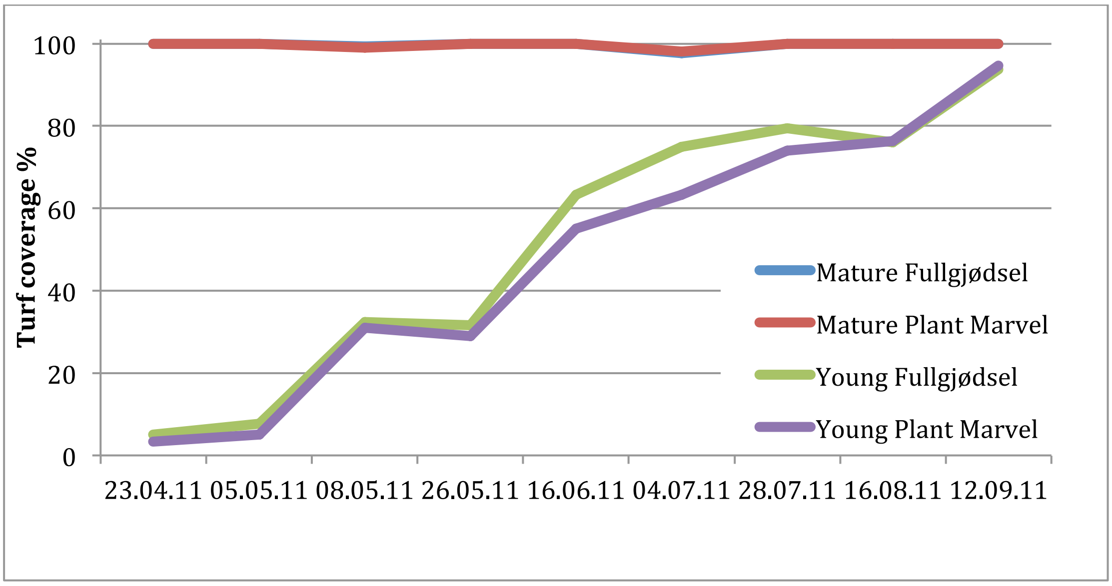


Figure 22: Effect of turf age (mature seeded in May 2010, young seeded in September 2010) and fertilizer type on turf coverage April 2011 until sod harvest. $P_{\text{interaction}}$= 0.02.

As a main effect, conventional granulated fertilizer resulted in slightly but significantly better turf coverage than liquid fertilizers. However, as indicated by the significant interaction sod age x fertilizer this differences only occurred from May to August 2011 for the younger turf seeded in September 2010 (Figure 22).

As a main effect, plots treated with biochemicals had a significantly darker color than plots not treated with biochemicals. For this character, there were also significant two and three -factor interactions. The interaction of sod age x fertilizer showed a beneficial response of Plant Marvel on the old turf, whereas the younger turf had a more positive response with Fullgjødsel. Secondly, biochemicals had positive effects on the younger Kentucky bluegrass dominated turf regardless of fertilizer treatment and on the older red fescue dominated turf that received Fullgjødsel, but not on the older red fescue dominated turf that received Plant Marvel (Figure 23).

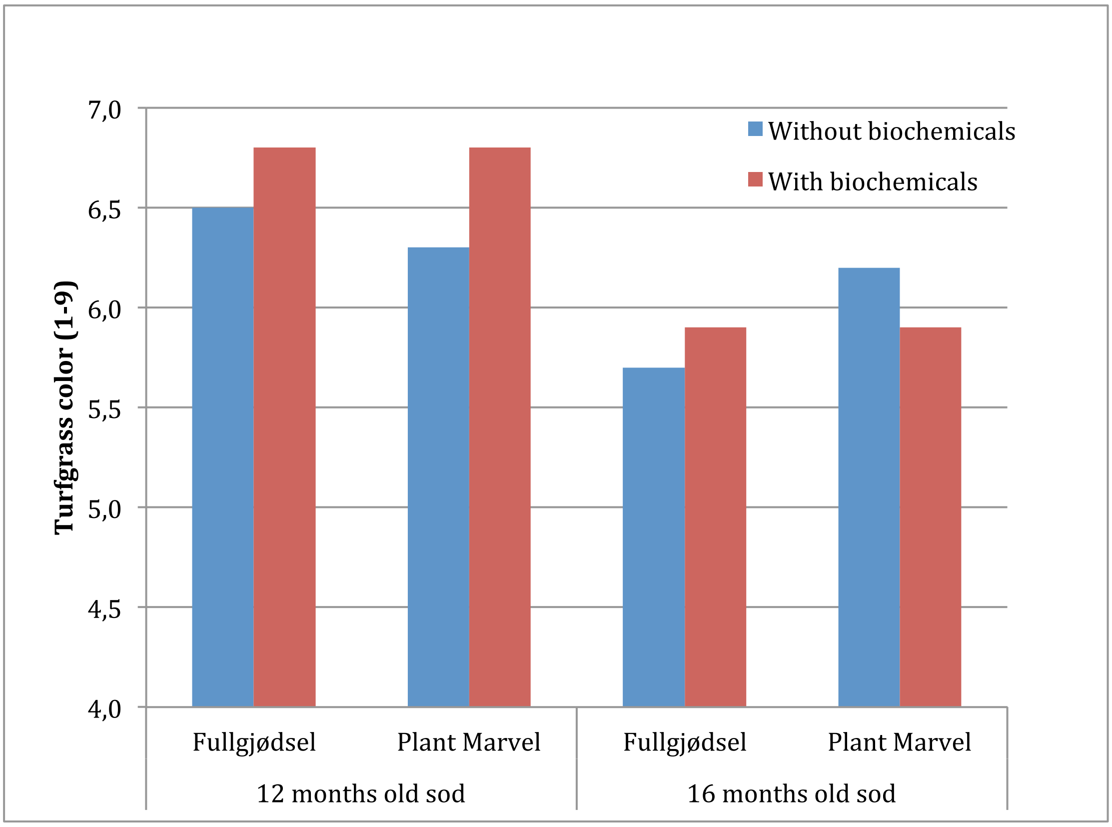


Figure 23: Combined effect of sod age, fertilizers and biochemicals on turfgrass color during the production period (mean of six ratings). $\boldsymbol{P_{\text{interaction}} = 0.05}$.

4.1.2 Species composition and tiller density

Main effects and significance levels for interactions are presented in Table 7, while the most important interactions are shown in Figures 24 and 25.

Table 7: Botanical composition - number of tillers of Kentucky bluegrass, red fescue, annual bluegrass, perennial ryegrass and total tiller density. Tiller countings was accomplished at sod harvest.

Factors	**Number of tillers per m2**				
Sod Age	**Kent. Bl.**	**Red. Fes.**	**Annu. Bl.**	**Rye Gr.**	**Total**
Mature (May 2010)	12717	29285	0	0	42002
Young (Sept 2010)	17924	1073	379	0	19376
***P*-value**	0.05	0.05	>0.15	-	0.09
Fertilizer					
Fullgjødsel	16851	13538	189	0	30579
Plant marvel	13790	16820	189	0	30800
***P*-value**	0.03	0.15	>0.15	-	>0.15
Biochemicals					
Without	14800	16126	252	0	31178
With	15842	14232	126	0	30200
***P*-value**	>0.15	>0.15	>0.15	>0.15	>0.15
Interactions (*P*-values)					
Sod age x fertilizer	>0.15	0.05	>0.15	>0.15	0.12
Sod age x biochemicals	>0.15	>0.15	>0.15	>0.15	>0.15
Fertilizer x biochemicals	>0.15	0.01	>0.15	>0.15	0.05
Sod age x fertilizer x biochemicals	>0.15	0.02	>0.15	>0.15	0.04

The species composition show a significant difference of Kentucky bluegrass and red fescue in the young and mature turf. The mature turf have a majority of red fescue (70% of tillers), while the younger turf has a majority of Kentucky bluegrass (93 % of tillers). Ryegrass was virtually absent regardless of sod age and annual bluegrass was found at low frequency in the young sod only (2 % of tillers).

Significant three factor interactions among sod age, fertilizers and biochemicals were observed for red fescue tiller number and total tiller number. Biochemicals had a small positive effect on the total tiller number on the young turf as well as the old turf receiving Fullgjødsel. But not on the older turf receiving Plant Marvel (Figure 24).

Figure 25 shows that these differences were mostly reflected in similar reaction patterns for red fescue tiller numbers.

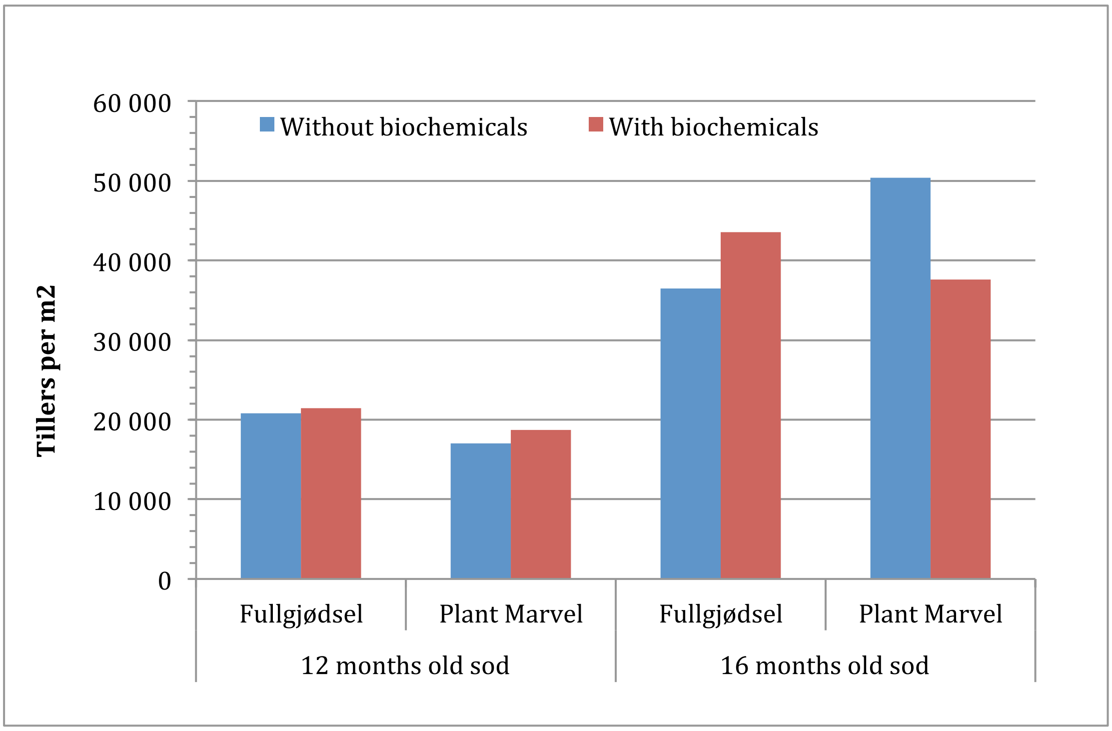


Figure 24: Combined effect of sod age, fertilizers and biochemicals on total tiller number at sod harvest. $P_{\text{interaction}}$= 0.04.

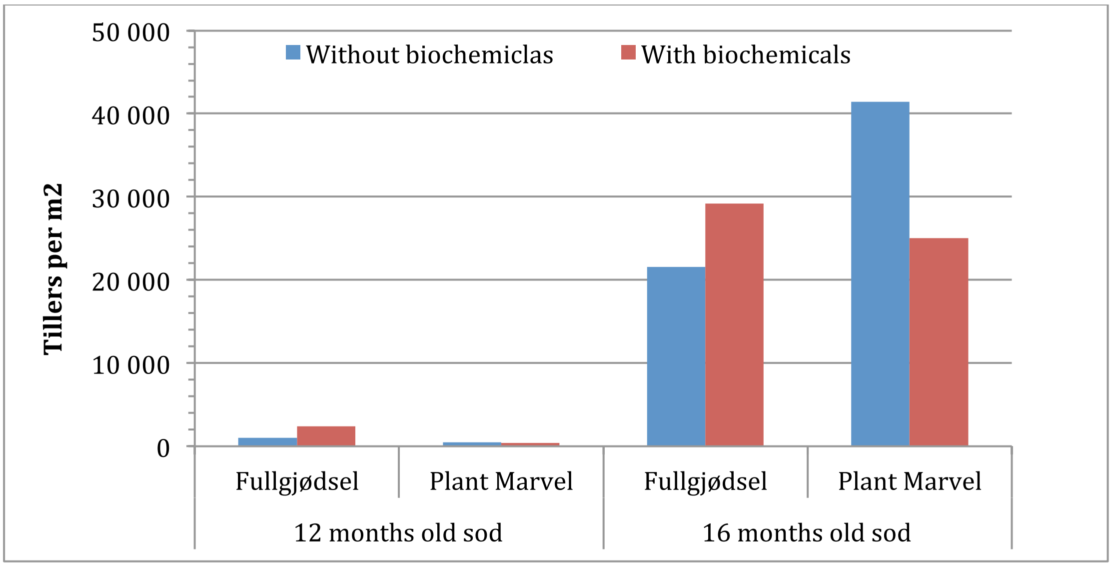


Figure 25: Combined effect of sod age, fertilizers and biochemicals on red fescue tiller number at sod harvest. $P_{\text{interaction}}$= 0.02.

4.1.3 Turfgrass shear strength and root development

Main effects and significance levels for interactions are presented in Table 8, while the most important interactions are shown in Figures 26 and 27.

Turfgrass shear strength at harvest tended to be higher for the young turf seeded in September than for the old turf seeded in May (Table 8). Neither fertilizers nor biochemicals affected this character significantly. As a main effect, the older turf had significantly more roots, in the 0-5 cm top layer, at sod harvest. As indicated by length of undisturbed cylinder samples, roots tended to go deeper under the young and immature turf. There was no significant main effect of fertilizers or biochemicals on any of these character, but significant or almost significant interactions suggested that biochemicals had a positive effect on root development on plots receiving Fullgjødsel but not on plots receiving Plant Marvel (Figure 26).

Table 8: Turfgrass shear strength and root dry weight at depths 0-5 cm (including thatch), 5-10 cm, under 10 cm and in total at sod harvest, 16 Sep. 2011.

Factors	**Shear strength (Nm)**	**Root depth (cm)**	**Root dry weight at sod harvest, g m^{-2}**			
Sod Age			**0-5 cm depth**	**5-10 cm depth**	**under 10 cm depth**	**Total**
Mature (May 2010)	40	22.9	563	91	80	734
Young (Sept 2010)	44	24.7	231	77	57	365
P-value	0.09	0.09	0.01	>0.15	>0.15	0.02
Fertilizer						
Fullgjødsel	42	23.8	372	86	78	536
Plant marvel	42	23.7	421	82	59	562
P-value	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15
Biochemicals						
Without	42	24.1	400	83	77	560
With	42	23.4	393	85	60	538
P-value	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15
Interactions (*P*-values)						
Sod age x fertilizer	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15
Sod age x biochemicals	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15
Fertilizer x biochemicals	>0.15	>0.15	>0.15	0.04	>0.15	0.09
Age x fertilizer x biochemicals	>0.15	>0.15	>0.15	>0.15	>0.15	>0.15

For root dry weight, there are two two-factor interaction results of interest. The combination of fertilizer and biochemicals showed one result of significance (P=0.04) and one result of tendency (P=0.09) of increased root production in the 5-10 cm deep layer as well as the total amount of roots in the soil with use of biochemicals together with Fullgjødsel. The opposite effect was registered with use of Plant Marvel together with biochemicals. Plant Marvel had a better increase on root production without biochemicals (Figure 26, 27).

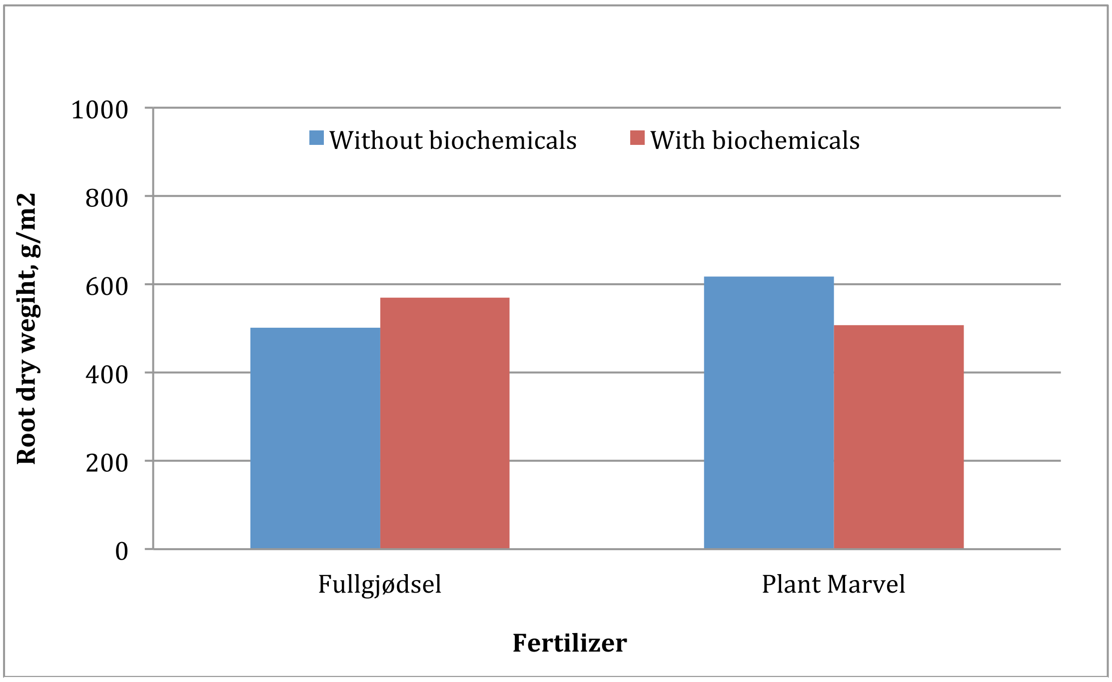


Figure 26: Combined effect of fertilizer and biochemicals on total root dry weight at sod harvest. Mean of 12 and 16 months old sod. $P_{\text{interaction}}$= 0.09.

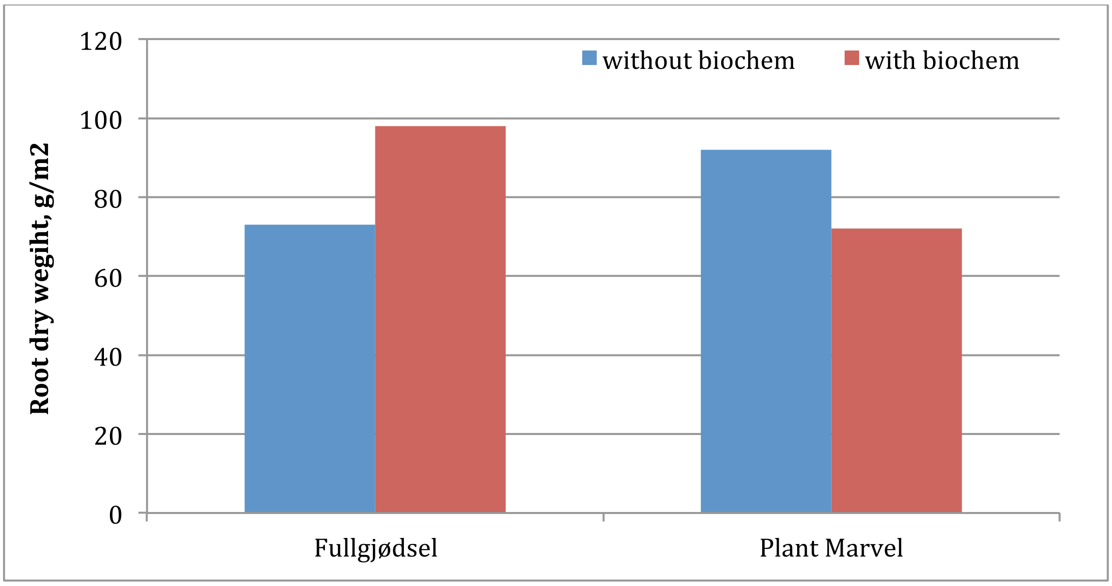


Figure 27: Combined effect of fertilizer and biochemicals on 5-10 cm depth root dry weight at sod harvest. Mean of 12 and 16 months old sod. $P_{\text{interaction}}$= 0.04.

4.2 Data collection post harvest

4.2.1 Rot development from sod

Main effects and significance levels for interactions are presented in Table 9, while the most important interactions are shown in Figures 28-30.

According to visual assessment two weeks after installation, significantly more of new white roots had emerged from the washed- than from the unwashed sod (Table 9).

However, this visual assessment was not confirmed by the washing and weighing of roots, 45 days after installation. For this character, the effects of sod age, fertilizer and washing were all insignificant, but there was a positive effect of biochemicals, although only on the young turf (Figure 28). There was also a significant interaction sod age x washing as rooting was reduced by washing for the mature turf only (Figure 29). Finally, there was a significant interaction of fertilizer x washing, as unwashed sod that had received Plant Marvel developed more roots than the other combinations. (Figure 30).

Table 9: Data collected of visual root assessment and root dry matter in grams per square meter, post harvest.

Sod Age	**Visual roots two weeks after installation (1-9)**	**root g DM m^{-2} after 6 weeks**
Mature (May 2010)	6.4	123
Young (Sept 2010)	6.5	103
P-value	>0.15	>0.15
Fertilizer		
Fullgjødsel	6.1	108
Plant Marvel	6.8	118
P-value	>0.15	>0.15
Biochemicals		
Without	6.2	105
With	6.7	121
P-value	>0.15	0.04
Washing		
UW	5.9	120
W	7.1	106
P-value	<0.0001	>0.15
Interactions (*P*-values)		
Sod age x fertilizer	>0.15	>0.15
Sod age x biochemicals	>0.15	0.06
Sod age x washing	>0.15	0.04
Fertilizer x biochemicals	>0.15	>0.20
Fertilizer x washing	>0.15	0.04
Biochemicals x washing	>0.15	0.15
Sod age x fertilizer x biochemicals	>0,15	>0.15
Sod age x fertilizer x washing	>0,15	>0.15
Sod age x biochemicals x washing	>0,15	>0.15
Fertilizer x biochemicals x washing	>0,15	>0.15
Sod age x fertilizer x biochemicals x washing	>0,15	>0.15

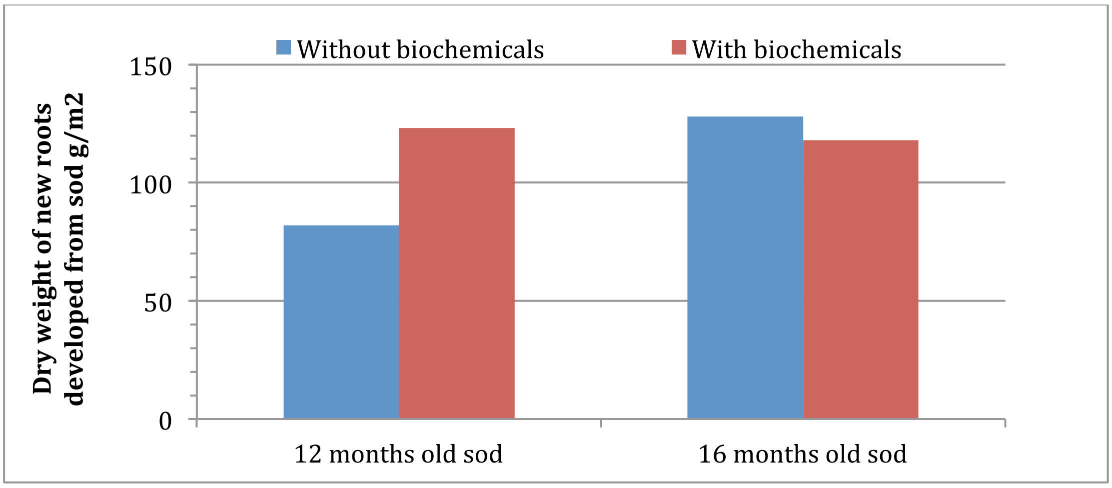


Figure 28: Combined effect of age and biochemicals on total root dry weight, post sod harvest. Mean of 12 and 16 months old sod. $P_{\text{interaction}}$= 0.06.

Figure 29: Combined effect of age and sod washing on total root dry weight post sod harvest. Mean of 12 and 16 months old sod. $P_{\text{interaction}}$= 0.04.

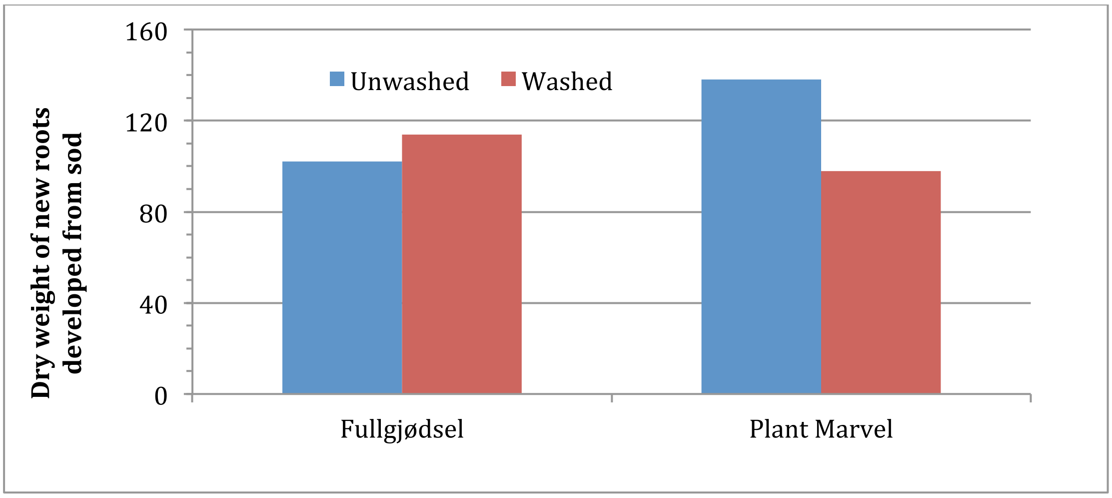


Figure 30: Combined effect of fertilizer and sod washing on total root dry weight post sod harvest. $P_{\text{interaction}}$= 0.04.

Visual characters and shear strength

Main effects and significance levels for interactions are presented in Table 10, while the most important interactions are shown in Figures 31-33.

On average for three assessments after installation, turfgrass general impression and color (freshness) tended to be better for mature than for young turf (Figure 33) and better for turf that had received Plant Marvel than for turf that had received Fullgjødsel. Apart from these tendencies, general impression and color were significantly reduced by washing. For general impression there were, however, significant interactions as the negative effect of washing was more pronounced on plots fertilized with Fullgjødsel than on plots fertilized with Plant Marvel (Figure 31), and more on plots without biochemicals, than on plots with biochemicals (Figure 32). The reduction in color (freshness of green color) because of washing was more pronounced for mature than for young sod (Figure 34).

Table 10: Data collected of general impr., color, and shear strength, post harvest.

Sod Age	General impression	Color	Shear strength (Nm)
Mature (May 2010)	6.6	6.4	41
Young (Sept 2010)	5.5	5.4	43
P-value	0.13	0.07	0.03
Fertilizer			
Fullgjødsel	5.6	5.6	42
Plant Marvel	6.5	6.2	42
P-value	0.09	0.02	>0.15
Biochemicals			
Without	6.1	6	43
With	5.9	5,8	42
P-value	>0.15	>0.15	>0.15
Washing			
UW	6.4	6.2	41
W	5.7	5.7	43
P-value	0.003	0.0009	0.05
Interactions (P-values)			
Sod age x fertilizer	>0.15	>0.15	>0.15
Sod age x biochemicals	>0.15	>0.15	>0.15
Sod age x washing	>0.15	>0.15	>0.15
Fertilizer x biochemicals	>0,15	>0,15	>0,15
Fertilizer x washing	0.05	>0.15	>0.15
Biochemicals x washing	0.04	>0.15	>0.15
Biochemicals x age	>0.15	>0.15	>0.15
Sod age x washing	>0.15	0.05	>0.15
Sod age x fertilizer x biochemicals	>0.15	>0.15	>0.15
Sod age x fertilizer x washing	>0.15	>0.15	>0.15
Sod age x biochemicals x washing	>0.15	>0.15	>0.15
Fertilizer x biochemicals x washing	>0.15	>0.15	>0.15
Sod age x fertilizer x biochemicals x wash	>0.15	>0.15	>0.15

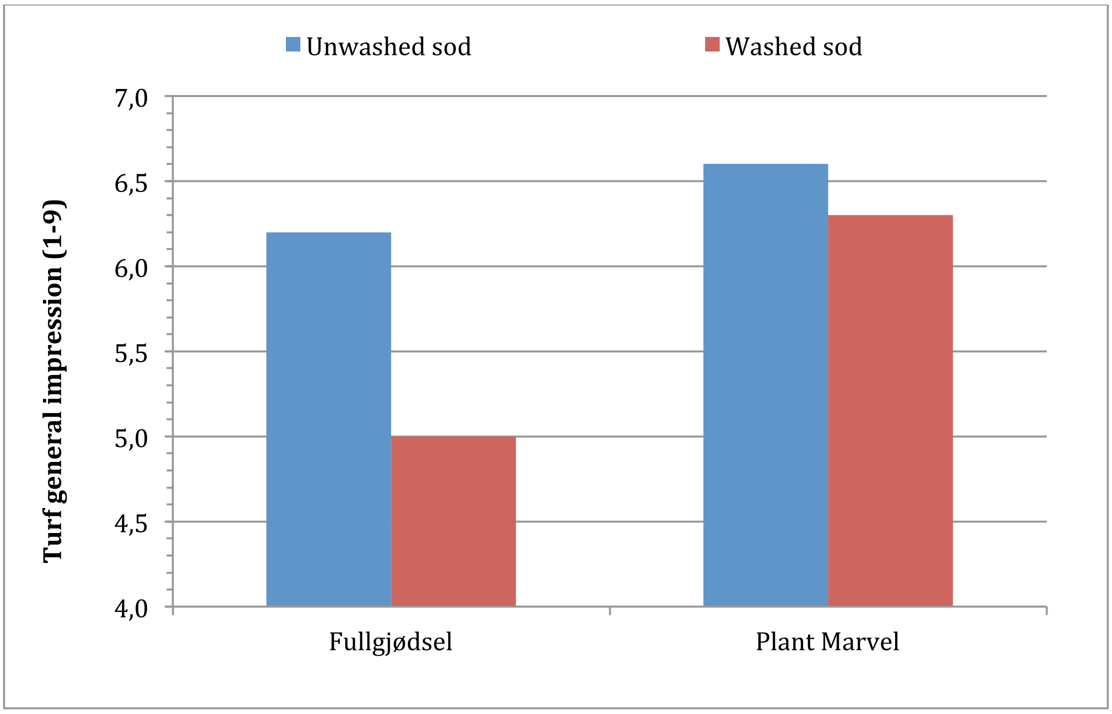


Figure 31: Combined effect of fertilizer during production and sod washing on turfgrass general impression after sodding. $P_{\text{interaction}}$= 0.05.

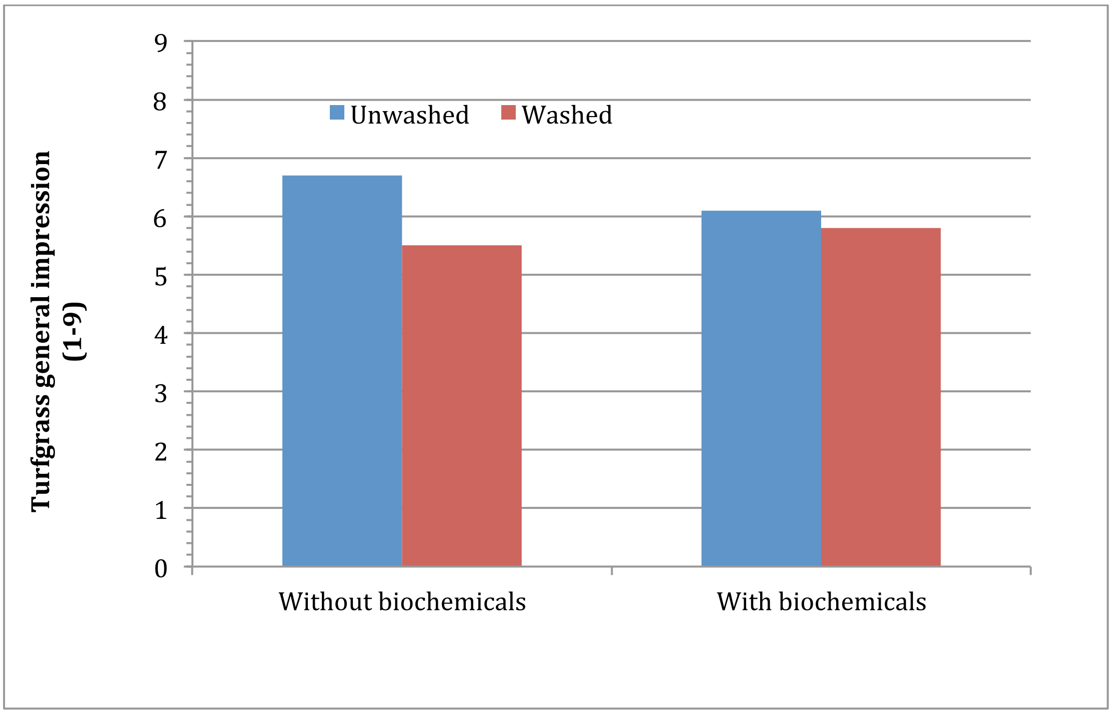


Figure 32: Combined effect of biochemicals during production and sod washing on turfgrass general impression after sodding. $P_{\text{interaction}}$= 0.04.

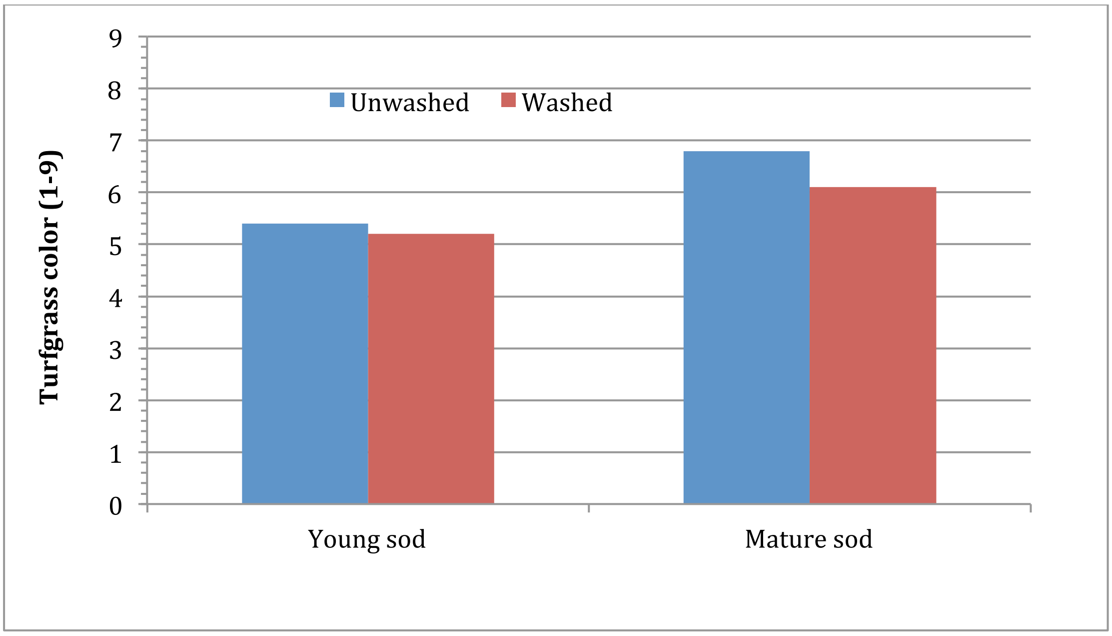


Figure 33: Combined effect of sod age and washing on turfgrass color after sodding. Scale 1-9, 9 is most freshly green. $P_{\text{interaction}} = 0.05$.

Figure 34: Sodded field at final assessment on 1 Nov. 2011. The color of young sod (four front rows) was inferior to that of old sod (four back rows), but the negative impact of washing was more conspicuous for the old turf. Photo: Trygve Aamlid

Shear strength gave a significantly better result on the younger grass and on turf that had been washed (Table 10). The main effects of fertilizers and chemicals, as well as all interactions, were not significant.

5 Discussion

Parts of the research topic of this thesis have been investigated previously, but hardly with the same combinations of experimental factors as in the present experiment. Indeed, it is the combination of factors and the many interactions that makes this research interesting and unique, but also difficult to interpret. For the Norwegian sod growers it is important to conclude about the potential reduction in sod production period and increase in sod quality that can be achieved through better technology and management practices. The discussion will as far as possible, be connected to the objective of the thesis and the thesis question.

5.1 Sod age and species composition

Sod age is an important factor in sod production. As stated in TPI´s quality grading, the turf has to reach a certain maturity before harvest (TPI, 1995). From the grower's point of view, the benefit of reaching the required maturity faster is less maintenance of the turf. A shorter production period will lead to decreased costs concerning mowing, irrigation, fertilizers and pesticides. Additionally, reduced maintenance work will lead to less compaction of the soil.

As showed in Figure 22, the turf needs time to achieve a certain density, but also a good root system that holds the sod together. A time period of 14-21 months is required from seeding until harvest (Hall III et al., 1985). Another study by the same author suggested a minimum of 18 months for sod consisting of tall fescue (90%) and Kentucky bluegrass (10%) (Hall III, 1980).

Norway has hard winters with restricted growing conditions, but cool temperatures in spring and fall are ideal for root development. The sod harvested in this experiment was 16 and 12 months old. The younger sod had barely reached a desirable shoot density at harvest, but even if it was less than 14 months old (Hall III et al., 1985), and was cut at only 15-17 mm the sod held together surprisingly well (figure 10).

If we were to grade the sod after TPI´s quality-grading system, the older sod would be characterized as a grade A, 'Premium'. The younger sod would be of grade B, 'Standard', primarily because it had a lower shoot density and higher weed content. It is, nonetheless, noteworthy that shear strength was higher for the young- than for the mature turf. So for certain purposes, such as football pitches, it might be argued that that the quality of the young sod was better than the older sod. The reason for this was species composition, as the old turf had a majority of red fescue tillers (70%), whereas the younger turf had a great majority of Kentucky bluegrass (93%) at harvest. In other words, sod age and species composition were confounded, which makes it impossible to determine if the effect of sod age was a true age effect or an effect of turf grass species composition.

Seeding of turfgrass mixtures in early spring will benefit fescues rather than Kentucky bluegrass. Research in Maryland (USA), showed that turf seeded in March and April had contained significantly more tall fescue, but less Kentucky bluegrass, than turf seeded in October (Hall III, 1980). It is normally recognized that turfgrasses seedlings have to reach a certain maturity to tolerate freezing temperatures (Stier et al., 2008), and vulnerability to frost at the seedling stage, this has been regarded as a special problem for tall fescue. Unfortunately, it has not been possible to find literature documenting the lethal temperatures for perennial ryegrass, red fescue and Kentucky bluegrass at various stages of seedling development, but in the present research, there is reason to believe that the winter temperatures of 2010/11 were low enough for immature seedlings of ryegrass and red fescue succumb during the winter. This explanation would need to be verified by more specific experiments, but it is in agreement with general Norwegian results and practical experience, giving Kentucky bluegrass, red fescue and ryegrass scores of 8, 7 and 3 concerning winter hardiness, respectively (Aamlid and Kvalbein, 2012).

The older turf had a total root dry weight of 563 g per m^2, in the upper 5cm of the soil, compared with 231 g per m^2 in the younger turf. To compensate for this, more soil would have to be harvested with the younger turf, and this can be an environmental-, as well as an economic issue for the producer. However, there was no problem with sod harvest despite the lower concentration of roots in the younger turf.

5.2 Fertilizers and biochemicals

Fertilizers and biochemicals had several interactions, and will therefore be discussed together in this chapter.

The soil sample taken prior to the first fertilizer application in May 2010 showed an acceptable content of all essential nutrients analyzed. The pH was also acceptable for grasses (Yara, 2010).

The total supply of nutrients with the four combinations of fertilizers and biochemicals is given in Appendix 1. Within each sod age, the amount of nitrogen was practically equal, but the four combinations supplied unequal amounts of the other nutrients.

Tom Ericsson of The Swedish Agricultural University (SLU) has contributed to a better theoretical understanding of plant nutrition. His objective has been to prescribe an ideal fertilizer composition without. paying attention to the soil's ability to provide nutrients by itself. One of his principles is that nitrogen should be the limiting factor, and additional fertilizers should be given as a ratio of nitrogen (Kvalbein, 2012, Ericsson, 1995). When compared with Ericsson's ratios, the four combinations of fertilizers and biochemicals mostly provided adequate amounts of the other nutrients, but some aspects warrant further discussion: (Table 11)

Table 11: Tom Ericssons model of nutrient supply in relation to nitrogen, compared with nutrient relation applied in research.

	N	K	P	Mg	S	Ca	Fe	Mn	B	Zn	Mo	Cu
Tom Ericsson	100	65	12	8	8	6	0,70	0,40	0,20	0,06	0,01	0,00
Fullgjødsel	100	89	16	9	27	8	0,00	0,22	0,13	0,02	0,00	0,00
Plant Marvel	100	89	13	7	0	5	0,44	0,23	0,07	0,21	0,02	0,23
Fullgjødsel with Biochemicals	100	102	22	9	27	10	1,31	0,22	0,21	0,24	0,00	0,22
Plant Marvel with Biochemicals	100	102	18	8	0	6	1,72	0,23	0,16	0,43	0,02	0,44

- Fullgjødsel supplied more P than Plant Marvel, and the supply was further increased by biochemicals. Ample supply of P is usually considered advantageous for turfgrass establishment (Carrow et al., 2001) This may be one of the reasons why Fullgjødsel provided better coverage of young, but not of the mature turf (Figure 22).

- Neither Plant Marvel nor the biochemicals contained sulfur. This nutrient is seldom deficient in turf but ample supply may help to alleviate turfgrass diseases (Carrow et al., 2001)
- Fullgjødsel did not contain any iron, and the Fe/N ratio in Plant Marvel was also lower than the ratio recommended by Ericsson. In both cases, the application of biochemicals contributed to increased supply of iron. Most likely, this is at least part of the explanation for the generally better color after use of biochemicals. The darker color connected with Plant Marvel after installation was also an effect of iron applied through Plant Marvel (figure 23 and table 6). Improved color through iron application and reduced nitrogen agrees with earlier research (Fermanian et al., 1984).
- The concentration of Zinc (Zn) in Plant Marvel and biochemical was three to four times higher than the levels recommended by Ericsson, and the combination of the two increased the ratio up to seven times the recommended rate. Excessive Zn levels are generally of more concern than Zn deficiency in turfgrass (Carrow et al., 2001). Antagonism between P and Zn is well recognized (Marschner, 1995) and inhibition of root growth by excessive Zn levels has been reported, although mostly at higher rates than those used in this experiment (Turner and Hummel Jr, 1992). Zinc is also known to interfere with the hormonal balance in turfgrass plants (Ervin and Zhang, 2008) Whether or not reduced color, tiller density and root development in the old red fescue dominated turf that received the combination of Plant Marvel and biochemical was related to zinc or hormonal imbalance remains a matter of speculation only.

Additionally to the ratio of nutrients given in relation to nitrogen, the form of which nitrogen is applied is of importance. In this experiment, Nitrogen was given as NO_3^-, NH_4^+ and CON_2H_4 The liquid Plant Marvel fertilizer had a majority of NO_3 and CON_2H_4 (table 5) and only a small proportion was given as NH_4^+. The proportion of NO_3^-N and NH_4^+- N in Fullgjødsel was approximately equal.

The climatic conditions in Table 3 shows a high amount of precipitation throughout the whole growing season. The high proportion of nitrogen given as NO_3^- and CON_2H_4 in Plant Marvel could indicate that much of the nitrogen was lost, due to leaching. Both NO_3^- and CON_2H_4 are easily leachable. Additionally, NO_3^- is susceptible to denitrification, where denitrifying bacteria convert NO_3^- into N_2 that escape into the atmosphere under wet conditions (Havlin et al., 2005). As stated in chapter 2.4.4 excess amount of nitrogen will promote factors such as grass color, shoot growth and shoot density, whereas lower amounts are more beneficial for root growth as well as rhizome- and stolon growth, which is closely correlated with carbohydrate reserves (Carrow et al., 2001). Although the effect was not significant, better development of new roots from that had received Plant Marvel might indicate that this turf had a lower nitrogen status at installation than turf that had received Fullgjødsel.

The effects of sod age / species composition are discussed in the previous chapter. However there was an interaction relating to fertilizers. Table 7 shows a significantly higher number of Kentucky bluegrass tillers with applications of Fullgjødsel. On the other hand, there was a trend to more red fescue tillers with Plant Marvel. In a correspondence with Dr. Eric Ervin. at Virginia Polytechnic Institute and State University, he stated; " From much experience and research, we know that Kentucky bluegrass is much more responsive (shoot, rhizome and root growth) to higher nitrogen inputs than red fescue. Applying over 135 kg N/ha to a red fescue sod will result in more tillering and thatch production at the expense of rooting, but this is not the case for Kentucky bluegrass (Ervin, 2012)" As high amounts of nitrogen will promote tillering in grasses and especially red fescue, it seems like nitrogen given to the mature turf was more than sufficient.

Use of biochemicals during the production phase resulted in significantly better root development after installation (Table 10). Root development rate is a key parameter of how fast the sod will produce roots down in to the soil, and the rate of which a consumer can use a lawn. A rapid recovery concerning general impression and rooting development post harvest, are key parameters to achieve a desired turf after installation. In a practical situation, this would certainly be desirable in a situation where a turf has to be established fast after installation. This is often the case whenever sport venues replace turf. The present results provide evidence that application of biostimulants before harvest will speed up sod grow-in after installation. process.

The interaction of fertilizers, biochemicals and sod age has already been discussed in relation to nutrient content but warrant an additional note in relation to sod age / species composition. The three-factor interactions were significant for both color (figure 23), and tiller number (figure 24 and 25), showing that biochemicals had the strongest effect on immature turf dominated by Kentucky bluegrass. Earlier research has found that biostimulants are more effective in Kentucky bluegrass than in fescues (Anonymous, 1989) and with Goatley and Schmidt who found biostimulants to be highly effective in Kentucky bluegrass at the seedling stage (Goatley and Schmidt, 1990). In a parallel experiment with crop plants, Kahn et al. (2009) found that Biostimulants gave a significantly better result for young than for old plants of maize. (Khan et al., 2009).

Extensive research concerning biostimulants and humic acids has been conducted by the turfgrass department at Virginia Tech. University. One of their reports showed increased root mass and leaf moisture in Penncross creeping bentgrass (*Agrostis stolonifera*), as well as increased root mass and higher concentration of vitamin E in Kentucky bluegrass. (Schmidt et al., 2003). It should be noted that both grasses were exposed for stressful conditions. The research concluded that the combination of humic acids and biostimulants, outperformed humic acids and biostimulants given separately. The research did not go into detail on which products were used, but the biostimulant applied was a seaweed *(Ascophyllum nodosum),* which is the same seaweed as Astron used in our experiment.

There were, however, also differences in experimental conditions between our experiment and the research by Schmidt et al. (2003). The fact that the summer of 2011 had beneficial growing conditions, with regularly precipitation, resulted in less stressful conditions growth of the established turf. By contrast, the turf that had been seeded in September 2010 had a higher concentration of weeds and was more easily exposed to drought in the early part of the season, because of its immature root system and low cover percentage. This was verified by early spring registrations, where the soil had cracks resulting from drought. Additionally the younger grass was exposed by more stress during the winter months, which proved to be lethal for both the red fescue and ryegrass. Carrow stated; “Caution is urged concerning cytokinin application on a turfgrass that is sufficiently healthy to produce and regulate its own cytokinin or hormone supply” (Carrow et al., 2001). In the older turf, results show beneficial response with Plant Marvel, but a negative response with biochemicals, when applied together. Carrows statement and the research by Schmidt et al. (2003) might be taken as an indication that biochemicals applied to an already healthy turf, might have a negative impact concerning sod color, tillers per m^2, as well as root dry weight. Additionally, this could also be an explanation why the positive effects are more prominent in the younger immature turf. However, this is only speculations, and would require further research.

5.3 Sod Washing

As washing was conducted at sod harvest, all results were collected post harvest. Table 9 shows data collected concerning roots. Visual root assessment resulted in significantly better grades for the washed sod, than the unwashed sod. This assessment graded the turf after its in rooting ability, how well the sod had attached itself to the soil, and it was also confirmed by measurements of shear strength. However, Figure 29 shows that the weight of roots developed from the sod was stimulated for the young Kentucky bluegrass-dominated turf only, while the opposite occurred for the old red fescue dominated turf.

Unlike the young roots and rhizome system of Kentucky bluegrass that was triggered by washing, the older and less active root system of red fescue was apparently disturbed to such an extent that the development of new roots was disturbed.

Washing of sod is usually conducted to make it compatible with sand-based root zones (Turgeon et al., 1978). This is a stressful operation that removes much of the nutrients in the soil attached in the sod, thus resulting in a lower general impression for a certain period, after sod installation. A major finding in the present research is that this reduction in general impression may be ameliorated by replacing Fullgjødsel with Plant Marvel and applying biochemical during the production phase.

This also supports the previous conclusion that biochemical will be most beneficial when the turf is exposed to some kind of stressful conditions.

Figure 35: Rooting / soil structure under unwashed (left) vs. washed (right) sod on 1. November, 45 days after installation. Plot 302 received Plant Marvel and biochemicals during the production phase. Photo: Trygve Aamlid

6 Conclusion

Replacing Fullgjødsel with liquid fertilizer will not decrease the production period. However, using Plant Marvel or biochemical can increase quality. But the effects are not additive.

As recommendation for sod growers, there is no reason to replace granular agricultural fertilizer with frequent applications of liquid fertilizers during the first part of the production period. However, during the last part of the production period, there may be advantages of applying liquid fertilizers or biochemicals, for the post harvest benefits of these products. In particular, this is the case if the sod is going to be washed prior to installation.

7 References

AAMLID, T. & KVALBEIN, A. 2012. Grasfrø til ulike typer grøntanlegg. *Bioforsk-konfernansen 2012* 7, 187-188.

AAMLID, T., L, N., F, E., F, V. & T, P. 2012. Engrapp eller raigras ved etablering og resåing av grasbaner i ulike landsdeler. *Bioforsk-konfernansen 2012,* 7, 179-181.

ANONYMOUS 1989. Biostimulant Research Findings Address Sod Production Problems. *Turf News,* 12, 52-55.

BEASLEY, J. & WILKINSON, H. 2008. Root Growth: Sod versus Seed (reality through research). *Turf News.*

BRADY, N. & WEIL, R. 2002a. *Elements of Nature and Properties of Soils,* Upper Saddle River, NJ, USA.

BRADY, N. & WEIL, R. 2002b. *The nature and properties of soils,* Upper Saddle River, N.J., Prentice Hall.

CANWAY, P. M. & BELL, M. J. 1986. An apparatus for measuring traction and friction on natural and artificial playing surfaces. *Journal of the Sports Turf Research Institute,* 62, 211-214.

CARROW, R. N., WADDINGTON, D. V. & RIEKE, P. E. 2001. *Turfgrass soil fertility and chemical problems: Assessment and management*, Wiley.

CHEN, Y. & SOLOVITCH, T. Effects of humic substances on plant growth. 1987. 412-412.

ERICSSON, T. 1995. Growth and shoot: root ratio of seedlings in relation to nutrient availability. *Plant and Soil,* 168, 205-214.

ERVIN, E. 2012. *RE: Kentucky bluegrass and red fescue characteristics.* Type to AAMLID, T.

ERVIN, E. & ZHANG, X. 2008. Impact of seaweed extract-based cytokinins and zeatin riboside on creeping bentgrass heat tolerance. *Crop Science,* 48, 364-370.

FERMANIAN, T., YUST, A. & WEHNER, D. 1984. Foliar application of N and Fe to Kentucky bluegrass. *Agronomy journal,* 76, 934-938.

FLORATINE 2012a. Astron. http://www.floratine.com.

FLORATINE 2012b. PK-Fight. http://www.floratine.com.

FLORATINE NORGE 2012a. Astron. http://www.floratine.no.

FLORATINE NORGE 2012b. PK fight. http://www.floratine.no.

GOATLEY, J. & SCHMIDT, R. 1990. Seedling Kentucky bluegrass growth responses to chelated iron and biostimulator materials. *Agronomy journal,* 82, 901-905.

HALL III, J. Effect of cultural factors on tall fescue--Kentucky bluegrass sod quality and botanical composition. 1980. American Society of Agronomy, 367-377.

HALL III, J., TAYLOR, L. & SHOULDERS, J. Sod strength and turfgrass quality of Kentucky bluegrass cultivars, blends and mixtures. 1985. 807-820.

HALL, J. 1993. Management to Maximize Sod Shear Strength and Sod Installation Rooting. *ASPA Turf News,* 17, 18-20.

HAVLIN, J., TISDALE, S., BEATON, J. & NELSON, W. 2005. *Soil Fertility and Fertilizers - An introduction to nutrient management,* Upper Saddle River, NJ, USA, Pearson Prentice Hall.

HESSELTINE, B. & SKOGLEY, C. 1978. Soil Loss and Organic Matter. *Turf News,* 1**,** 4-12.

HILLEL, D. 2004. *Introduction to Enviromental Soil Physics*.

HOPKINS, W. & HÜNER, N. 2008. *Introduction to plant physiology,* Hoboken, NJ, John Wiley & Sons.

HURTO, K., TURGEON, A. & SPOMER, L. 1980. Physical characteristics of thatch as a turfgrass growing medium. *Agron. J,* 72**,** 165-167.

KHAN, W., RAYIRATH, U., SUBRAMANIAN, S., JITESH, M., RAYORATH, P., HODGES, D., CRITCHLEY, A., CRAIGIE, J., NORRIE, J. & PRITHIVIRAJ, B. 2009. Seaweed Extracts as Biostimulnats of Plant Growth and Development. *J Plant Growth Regul,* 28**,** 386-399.

KVALBEIN, A. 2012. Riktig gjødsling gir sterkt gress. *Bioforsk FOKUS,* 7**,** 182-184.

LANDSCHOOT, P. 2003. Turfgrass fertilization: A basic guide for professional turfgrass managers. Pennsylvania State University.

LIU, C. & COOPER, R. 1999. Humic substances, their influende on creeping bentgrass growth and stress tolerance. *Turfgrass trends* 7**,** 6-12.

LYONS, E. & O´CONNOR, K. 2008. Beyond the surface - The movement of foliar fertilization. *Greenmaster,* 43**,** 22-25.

MARSCHNER, H. 1995. Mineral Nutrition in Higher Plants. *Plant, Cell and Environment,* 11.

MILLAR, D., STOLT, M. & AMADOR, J. 2010. Quantification and Implications of Soil Losses from Commercial Sod Production. *Soil Sci. Soc. Am. J.,* 74**,** 892-897.

MOLTEBERG, B. & AAMLID, T. 2007. Nordisk sortsguide for gras i grøntanlegg, 2007. *Bioforsk FOKUS,* 2.

RAYORATH, P., KHAN, W., PALANISAMY, R., PRITHIVIRAJ, B., MACKINNON, S. L., STEFANOVA, R., HANKINS, S. D. & CRITCHLEY, A. T. 2008. Extracts of the Brown Seaweed Ascophyllum nodosum Induce Gibberellic Acid (GA3)-independent Amalyse Activity in Barley. *J Plant Growth Regul,* 27**,** 370-379.

REPSTAD, J. 2005a. Opptak av næring i blad. *Gressforum,* 4**,** 18-19.

REPSTAD, J. 2005b. Opptak av næring i røtter. *Gressforum,* 3**,** 20-21.

RESIETTER, D. 2001. The Enviromental and Economic Benefits of Netting in Turfgrass. *Turf News,* 25**,** 44-49.

RICHTER-RASEN. 2012. *About Richter-Rasen english* [Online]. http://www.richter-rasen.com/english/index.html.

ROLAWN. 2012. *About Rolawn* [Online]. http://www.rolawn.co.uk/about-rolawn.html: Rolawn 2012.

SCHMIDT, R., ERVIN, E. & ZHANG, X. 2003. Questions and answers about biostimulants. *Golf Course Management,* 71**,** 91-94.

SKOG OG LANDSKAP. 2012. http://www.skogoglandskap.no [Online]. Available: http://www.skogoglandskap.no.

STIER, J. C., KOERITZ, E. J. & GARRISON, M. 2008. Timing the Establishment of Kentucky Bluegrass: Perennial Ryegrass Mixtures for Football Fields. *Hortscience,* 43**,** 240-244.

TPI 1995. *Guideline Specifications to Turfgrass Sodding*, Turfgrass Producers International.

TURGEON, A., WARREN, B. & BERNS, F. 1978. A Mechanized Washing System for Generating Soil-Less Sod. *Agronomy journal,* 70**,** 349-350.

TURNER, T. R. & HUMMEL JR, N. W. 1992. Nutritional requirements and fertilization. *Agronomy*.

VARSHOVI, A. 1996. Humates and their turfgrass applications. *Golf Course Management,* 64**,** 53-56.

YARA 2010. *Gjødselhåndbok*.

ØIEN, A. & KROGSTAD, T. 1989. Jordanalyser - Teori metoder og apparatur. 1**,** 74-82.