Control of docks (*Rumex spp.)* in organic fodder production – a true bottleneck in organic farmed branded dairy and meat products

Project description PART 1: The KMB project

Summary
Control of dock species are a true bottleneck in the development of grassland based organic production in Norway. *Rumex obtusifolius, Rumex crispus* and *Rumex longifolius* are among the most important perennial weeds in grassland areas throughout the world. These docks are undesirable in grasslands because they decrease yields and reduce forage feeding value. Numerous farmers feel powerlessness regarding how to manage the *Rumex* problem. Some farmers continue conventionally farming instead of organic, although they generally are motivated for transferring to organic production, due to the dock problem.

The main goal of the project is a high quality and stable production of regional branded dairy and meat products based on fodder from grassland with non-chemical control of docks. This is to be achieved through knowledge on important factors that influence severity of dock infestation, studies on weak growth stages of docks, evaluation of biological control of docks and a synthesis of various measures to control these weeds.

The return of the efforts of the project is increased organic production of meat and dairy products.

1. Objectives

Main objective
High quality and stable production of regional branded dairy and meat products based on fodder from grassland with non-chemical control of dock

Sub objective 1
Reduce infestation of *Rumex spp* through knowledge on relationship between severity of dock infestation and grassland management, soil physical and chemical factors and site specific genetic variation.

Sub objective 2
Improve dock control measures through a description of a life table of *Rumex longifolius* and evaluation of weak growth stages with emphasize on germination and early growth of seedlings.

Sub objective 3
Evaluate potential for biological control of *Rumex spp* by natural enemies occurring in Norway.

Sub objective 4
Optimize control of docks in organic farming by integrating possible control measures and grassland management practises of grass-legume leys to promote competitive ability against taller *Rumex spp*.

2. Frontiers of knowledge and technology

Introduction
Rumex obtusifolius, Rumex crispus and *Rumex longifolius*, in this research proposal defined as «taller *Rumex* species» or «docks», are among the most important perennial

weeds in grassland areas throughout the world (Zaller 2004b). These *Rumex* species are undesirable in grasslands because they decrease yields and reduce forage feeding value (e.g. Marten et al. 1987). Experiments have shown that ten *R. obtusifolius* plants per m^2, similar to 30% ground cover, may reduce total yield in perennial ryegrass sward by 30% (Oswald & Haggar 1983). Zaller (2004b) has recently reviewed ecology and non-chemical control of *R. crispus* and *R. obtusifolius*, and stated that *Rumex* infestation has increased on arable land during the last decades. He suggests that the reason for this should be investigated to enable us to take the right measures to reduce their competitiveness. Galler (1989) estimated for Central Europe that more than 80 % of all herbicides used in conventional grassland farming were used to control taller *Rumex* species. The needs for herbicide application in conventional farming clearly demonstrate the challenge for organic farming and the need for more knowledge about biology and ecology of these *Rumex* species as well as non-chemical measures and strategies. In a recently published report Anderson (2005) from Sweden presents the following strong statement about taller *Rumex* species dimensions in organic grassland production: «*Många lantbrukare känner sig i dag makteslösa och vet inte hur de ska hantera dette ogräsproblem. Det finns i dag producenter som avstår från att ställa om til ekologisk produktion, eftersom de ser små möjlighter att bekämpa skräppor (Rumex spp.) i ekologisk produktion*». (in eng. «Numerous farmers feel powerlessness regarding how to manage the *Rumex* problem. Some farmers continue conventionally farming instead of organic, although they generally are motivated for transferring to organic production, just because the *Rumex* problem»). The situation is quite the same in Norway (see the attached letters of this proposal).

Ecotypes of *R. longifolius* and differences between taller *Rumex* species
In the international literature *R. crispus* and *R. obtusifolius* are the most widespread and refereed species (search in the ISI-database gave 274 results), however *R. longifolius* is the most widespread (Fykse 1986) of the three species in Norway (search in the ISI-database gave only 2 results). *R. longifolius* grows all over Norway and in the mountain areas it is found even at heights of 1250 m above sea level. On the other hand *R. crispus* and *R. obtusifolius* belong mainly to the coastal districts, where they are widely distributed from the Swedish border along the coast northwards to Nordland and Troms (Lid 1979). In Sweden, *R. crispus* is the most common species, but the distribution of *R. obtusifolius* and *R. longifolius* are increasing (Andersson 2005). With some exceptions, e.g. Fykse (1986), rather few scientists have compared the biology and ecology for all these three *Rumex* species. However, many examples of differences between *R. crispus* and *R. obtusifolius* are mentioned further on in this proposal.

According to Zaller (2004b) *R. crispus* and *R. obtusifolius* are known, at least for to some degree, to be indicator plants of agricultural mismanagement. *R. crispus* is e.g. mentioned to indicate soil compaction (Ellenberg 1986; Obendorfer 1990). Whether soil properties are key factors for explaining the distribution of the taller *Rumex* species is not known.

Experiments by Fykse (1986) showed that in spring *R. longifolius* developed much faster than the two other species. *R. obtusifolius* demonstrated the slowest growth rate. After first harvesting the situation was opposite, the regrowth started faster in *R. obtusifolius* and *R. crispus* than in *R. longifolius*. Fykse (1986) showed differences between species in root biomass level as well as root biomass development during stem elongation. Furthermore, *R. longifolius* formed twice as many shoots from root pieces compared to the two other species.

A Finnish study by Holm & Korpelainen (1999) showed that morphological variables, e.g. the shapes of leaves in *R. longifolius* changed along a gradient ranging from northwestern to southeastern Fennoscandia. However, a clustering analysis showed that the genetic features of *R. longifolius* populations did not display comparable geographical differentiation as did the morphological variables.

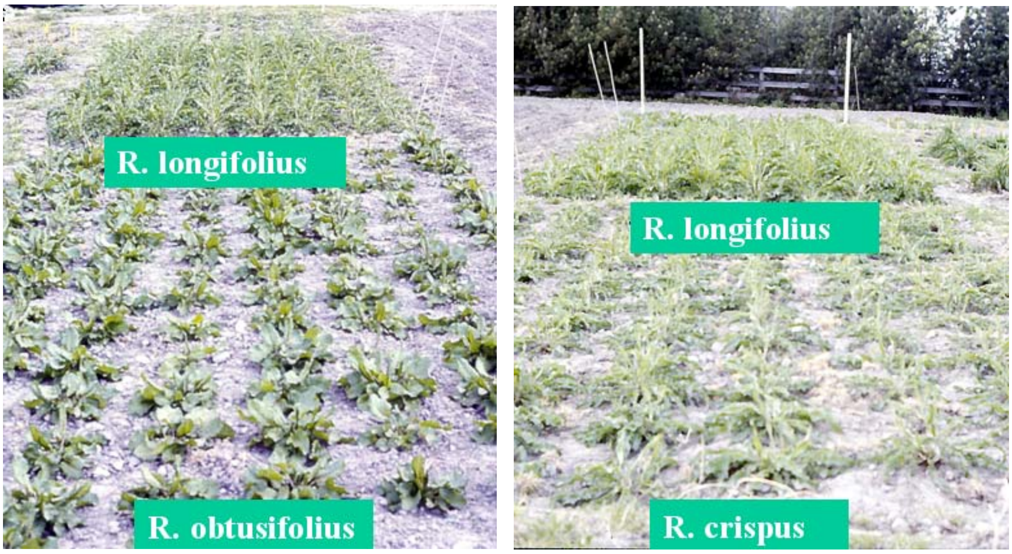

Figure 1. A study in Norway by Fykse (1986) showed that *R. longifolius* developed much faster than the two other species in the spring and early summer before harvesting (Photo: Haldor Fykse).

Biology / Life strategies
No clear data are available on the longevity of *Rumex* plants, but it is observed that some plants live for decades. Neither *R. obtusifolius* nor *R. crispus* occur in higher abundance in native plant communities, but are clearly stimulated and distributed by human activities (Ellenberg 1986).

Flowering and seeds
Flowering and seed production can occasionally happen in the year of seeding but usually takes place in the second year, from the spring and until hard frost in late autumn. It is reported that *R. obtusifolius and R. crispus* have some tendencies to die after producing seeds. Studies have shown that a) 6 days after end of first flowering, 15% of the seeds were viable, and b) similar number after 18 days, were more than 90% (Dierauer & Stöppler-Zimmer 1994).

One single plant can add thousands of seeds to the soil seedbank, but mortality of seeds in the soil is high. Having said that, some seeds remain viable for about 80 years. Several reports conclude that seed germination of *R. obtusifolius* and *R. crispus* is promoted by light and alternating temperatures (e.g. Weaver & Cavers 1979b). There are clear flushes of germination in early spring and early summer autumn when strong temperature fluctuations between day and nigh occur (Roberts & Totterdell 1981). However, light requirement for germination of buried seeds may fluctuate dramatically with time. Studies have also shown that germination ability dependent of time of seed development on the mother plant. Seeds of *R. obtusifolius* are somewhat slower in germination than those of *R. crispus* (Cavers & Harper 1964). There are no reports on germination of *R. longifolius* compared to these species.

spring	summer	autumn	winter	spring	summer	autumn	winter	…..
Year 1				Year 2				…….

Figure 2. *R. obtusifolius*, *R. crispus* and *R. longifolius* are classified as stationary perennial plants. Flowering and seed production usually takes place in the second year (Illustrator: Hermod Karlsen).

Seedlings, growth and development.
Similar to germination, seedlings of *R. obtusifolius* are shown to be somewhat slower in early development than those of *R. crispus. R. obtusifolius* and *R. crispus* have low competitive ability as seedlings, and can not establish in closed communities. Probably is the same true for *R. longifolius.* Haugland (1993) found that *R. longifolius*-seedlings had good adaptability to low light intensities. The plants did not grow fast under low light conditions, but still did not die. In established grassland communities we believe that seedlings can only establish in grassland gaps. This is, however, under investigations in an ongoing PhD-thesis in Sweden (Alexandra Pye, pers. communications).

Knowledge about seeds and vegetation ecology has been highlighted, but this knowledge is mainly derived from laboratory and greenhouse studies. Although there is high focus on seeds, there is a lack of data on germination and dormancy of seeds under field conditions. As already pointed out, studies have shown clear flushes of germination of *R. obtusifolius* and *R. crispus* in early spring/summer and autumn when strong temperature fluctuations between day and night occur. It is important to investigate whether this also is true for *R. longifolius*. Some reports conclude that regeneration from root parts of *R. obtusifolius* and *R. crispus* mainly occur during early spring and one essential question is whether this is true also under Norwegian conditions with short spring and whether *R. longifolius* behave similar as the other two species. However, studies including all the three *Rumex* species by Fykse (1986) showed that the developmental stages of the docks probably is more important than date of the growth season. These questions are highly related also in the practical point of view, and the applied aspects is whether farmers should renew the grassland in mid-summer for preventing /decreasing the flush of both seedlings from seeds and shoots from root fragments.

Root ecology and regeneration.
Exhaustive knowledge of the root system is imperative for the development of sustainable control strategies against the *Rumex* species. The taller *Rumex* species have a true clonal growth system and vegetative shoots may be the most usual regenerative system in dense swards. Seed dispersal and seedling establishment would remain the strategy for colonizing gaps in the sward and for maintaining genetic variability of the population.

Clonal growth appears from:
- The subterranean stem parts (i.e. the rhizome)
- New taproots

Almost all 3-year old plants develop secondary taproots, and 5-year old or older are usually heavily divided as secondary taproots become the main root system. Root longevity of *R. obtusifolius* was estimated to be less than 2 years in fertile soil and more than 4 in infertile soil, but most likely much longer (Zaller 2004b).

Most studies conclude that regeneration of shoots only can take place from the uppermost part (5 upper cm) of the taproot (e.g. Healy 1953, Fykse 1986, Pino et al. 1995). However, some contradicting results are also found, but can most likely be explained by difficulties in distinguishing between root and rhizome parts of below ground plant parts (Zaller 2004b). Experiments have shown that rhizomes (underground parts of stem) of *R. obtusifolius* can regenerate down to 20cm burial depth, but not from 30cm.The root system of hybrids between *R. crispus* and *R. obtusifolius* seem to have slightly greater regenerative ability than the parents (Cavers and Harper 1964). Pool size of reserves stored in roots is probably the best measure of the potential to contribute to future growth. Mono- and disaccharides can make up more than 50% of total sugar.

There is a wide body of literature (see Hatcher & Melander 2003; Zaller 2004b) about cutting time and cutting frequency of *Rumex* species, and it is clear that cutting must be done very frequently for controlling these species. We can conclude that cutting every second week, which is necessary to control these species, not is practically useful knowledge for farmers in ordinary grassland production. However, basic knowledge about root ecology, especially the compensation point (the dry matter minimum point during shoot development) for aboveground plant parts, would be very useful knowledge especially when renewing grassland. Norwegian studies by Fykse (1986) have indicated that differences occur between the taller *Rumex* species. Knowledge about the compensation point is essential for deciding the optimal time for disturbing plants either by cutting or soil tillage. Questions to be answered, should include the compensation point for whole plants (undisturbed roots) as well as shoots from root fragments, and finally the studies should include all the three taller *Rumex* species. It should be added that cutting is important for preventing seed production and increased seed bank. Preventing seed production of small *Rumex* plants after the last harvesting is also important.

Natural enemies

Numerous predators and parasites have been identified on *R. crispus* and *R. obtusifolius* (Zaller 2004b.). Only a few of them are damaging enough to be a potential bio-control agent. The most thoroughly studied organisms for *Rumex* control are the Coleoptera *Gastrophysa viridula* Degeer and the rust fungus *Uromyces rumicis* (Schumach) G.Winter. *Rumex* plants were rarely so badly attacked by these beetles that they died out as a consequence, unless some other agent further weakened the plants. Under controlled conditions Moore et.al., (2003) found that *Coleoptera* beetles kept in clip cages managed to systematically reduce *R. obtusifolius* leaf area even after the cages had been removed. Rust fungus as bio-control agent on *Rumex* was intensively studied earlier in the 1960s by the USDA, and although showed signs of success on *R. crispus* the project was terminated and the rust was not allowed to be imported into the US as the plant host for the sexual stage of the rust was unable to be confirmed.

At present the most promising result is from studies of interactive effects between foliar fungal pathogens with combination of rust fungus and Coleoptera (Hatcher et. al 1994 a,b, 1997; Hatcher. 1996; Hatcher & Paul 2000) (Keary & Hatcher 2004). The studies clearly demonstrate the possibility to control *Rumex* species with a combined application of herbivores and fungi. Introducing or stimulating predators and parasites can be a part of a regime to avoid the worst negative effect of the species.

The augmentation approach of biological control employs a native pathogen or pest by adding excessive inoculum that promotes a quick epidemic spread. Development of such systems requires a case-by-case study for the actual weed problem (Müller-Schärer og Scheepens 1997, Charudattan 2001). However, there is no study on natural enemies on *R. longifolius*, the most wide spread species in Norway. The fungus *Ramularia rubella* is very common on *R. longifolius* in Norway, but a further inventory of natural enemies in Norway on the *R.* species and in particularly *R. longifolius* is needed. In the UK there is an aphid (*Aphis rumicis*) and a leaf-mining fly (*Pegomya sps*) which causes some damage, but will not control the plants.

Integration of non-chemical control measures of *Rumex* in organic farming

Mechanical measures

Cutting, number and time of, as well as pulling by hand are the dominant mechanical measures. Pötsch (2003) established a weed threshold, around 2000 *Rumex* plants hectare^{-1}, when single plant control in grassland becomes uneconomical. During the last years hand or machine pulling has rarely been studied, but Pötsch (2003) did compare a new motor-driven dock pulling machine which can pull about 600 *Rumex* plants per hour (6sec/plant), hand-pulling (23sec/plant) and hand infrared flaming (50sec/plant). Cutting has been the topic of numerous studies, and as expected the number of cuttings and the effect on *Rumex* is positively correlated. However, cutting frequency has also shown to affect the *Rumex* species differently. Most investigations show that cutting must be done very frequently for controlling these species. Even with five to seven cuttings per season *Rumex* abundance was reduced only by 60% after 6 years. (Courtney 1985). Consequently, Zaller (2004b.) concluded that cutting every second week is necessary to control these species.

Cultural methods - Preventive measures

Direct measures as biological control, pulling, cutting etc. mainly aim at reducing or eliminating existing *Rumex* infestations, in contrast cultural methods aim to prevent or reduce the problem before it's become a problem by doing changes in cultural practice justified by experiment or experiences.

Cultural methods - Soil tillage

Renewing heavily infested leys is one important control measures of *Rumex*. Roto-tilling or shallow ploughing may be one strategy for severing the plants below the shoot buds and thus prevent the taproot from regenerating. Tillage has however, also been reported to stimulate *Rumex* distribution in arable land (Dierauer & Stöppler-Zimmer 1994). This paradigm, either stimulation or prevention by soil tillage, is well known for numerous weeds (Håkansson 2003). Hence it is of paramount importance to establish the best preventive tillage implements and methods. After soil tillage *Rumex* populations are frequently re-established recruitment from the soil seed bank and reestablishment from root fragments would be the most important way for regeneration of (Pino et al. 1995). Because *Rumex* seeds are stimulated by light it seems naturally to assume that soil tillage in darkness may reduce germination and emergence (Zaller 2004b). Season time of soil disturbance may also make big differences to the germination dynamics of weed populations, e.g. soil disturbance in late summer has been suggested to stimulate the growth of *Rumex* populations (Weaver & Cavers 1979a; 1979b).

Cultural methods – Competition

The literature and practical experience tell us that *Rumex* seedlings often are found only on bare grounds and that their growth is negatively affected by shading indicate that control through competition for light should be successful (Zaller 2004a). A dense competitive sward, including both choice of competitive species cultivars and high seeding rates and moderate fertilization are important tools as parts of a preventive strategy. Additionally, for increasing the grass species competitive ability, reseeding in a dock-infested field must be as soon after soil cultivation as possible (Kearny & Hatcher 2004). High fertilization rate is commonly stated as a key-factor for increasing the growth of *Rumex*, but rather few studies are supporting this statement (Zaller 2004b). Nitrogen and potassium are known to stimulate the development of taller *Rumex* species (Humphreys et al. 1999). However, also Hatcher et al. (1997) showed that R. obtusifolius responded well to extra soil nitrogen fertilization, but so did the bettle and rust as well, and the plant could not escape. There are however some doubts as to whether the *R. obtusifolius* and *R. crispus* are nitrophilous in all developmental stages. *R. crispus* shows lesser requirement for soil nutrients but a higher requirement for soil moisture than *R. obtusifolius*.

Allelopathic effects of *R. obtusifolius* have been shown, but these studies have been conducted under controlled conditions and it remains to be shown if findings are consistent under field conditions (Zaller 2004b).

3. Research tasks

Dock species are a true bottleneck in the development of grassland based organic production in Norway. There is a wide literature on dock species like *R. obtusifolius* and *R. crispus*, while literature on the main dock species in Norway, *R. longifolius*, is limited. Some of the knowledge is transferable between dock species, but still there is important knowledge to be gained to improve control of docks and hence the increase production of dairy and meat organic production.

Tasks related to sub objective 1

- What is the genetic variation of dock clones in Norway and do this variation influence dock infestation?
- How does grassland management influence dock infestation?
- How do soil physical and chemical factors influence dock infestation?

Tasks related to sub objective 2

- Is there a variation in dock germination through the growing season?
- Is there a variation in shoots sprouting from root fragments through the growing season and how important is the docks developmental stages?
- How do light and temperature fluctuations influence germination of *R. longifolius*?
- How does competition at various developmental stages influence nutrient reserve level in the dock root?

Tasks related to sub objective 3

- Are there virulent isolates of pathogenic fungi in Norwegian *Rumex* populations?
- Are there efficient herbivores on *Rumex* in Norway?
- Are these organisms per se or in combinations potential tools to control the target weeds?
- How are the host specificity of the organism, are off target effects likely?

Tasks related to sub objective 4

- What is the long term effect of non-chemical control of *Rumex*?
- What are the optimal soil tillage operations, equipment and timing to control *Rumex*?
- What length of the black fallow period is acquired?
- What can be achieved by integration of the mentioned mechanical control measures with competitive grass crops?

4. **Research approach, methods**

Sub objective 1
Reduce infestation of Rumex spp through knowledge of relationship between severity of dock infestation and grassland management, soil physical and chemical factors and site specific genetic variation.

WP 1.1 Relationship between infestation and grassland management, soil factors and ecotype

a) To investigate the relationship between *Rumex* infestation and grassland management, soil factors and ecotype, 50 locations with various ecotypes will be analysed each year in two years.

Ten locations in the main dairy and meat producing area of Norway will be selected for the surveys. Within each location five fields showing a variation in *Rumex* densities will be chosen. The difference should not be due to recent chemical application or different age of the leys. At each site severity of infestation will be registered together with soil physical parameters (static penetration resistance, grain size distribution) and soil samples for chemical soil properties. *Rumex* plants (clones) will be collected in each field and classified, based on phenotypic variation as *R. obtusifolius*, *R. crispus* and *R. longifolius*.

The genotype of selected plants will be screened by DNA-based methods. The DNA sequence of the internal transcribed regions ITS1 and ITS2 of the ribosomal DNA will be amplified and sequenced using universal primers (White et al. 1990) as well as *Rumex* specific ITS-primers (Navajas-Perez et al. 2005) to verify the plant species and identify possible hybrid plants. The selected plants will then be further genetically characterized by AFLP (amplified fragment length polymorphism) and/or RAPD (random amplified polymorphic DNA), methods previously used for successful genetic analyses of *Rumex* species (Holm and Korpelainen 1999; Stehlik 2002; Jin et al. 2004).

Relationships between severity of infection and phenotypes, genotypes, soil physical and chemical factors and grassland management factors will be analysed by various multivariate methods.

WP 1.2 Relationship between competition and soil N and K.

To study the effect of various potassium and nitrogen levels on growth and development of *R. longifolius* a greenhouse experiment will be set up. Various potassium and nitrogen levels will be in combination with competition from a grass species. Ryegrass will be used, since this species is well known for its affinity for N and K. To establish the growth dynamics of both *R. longifolius* and ryegrass at least five harvests of separate plants will be conducted. At each cut plants are separated in root and shoot parts. Plant parts will be analysed for N and K concentration.

Sub objective 2
Improve dock control measures through a description of a life table of R. longifolius *and evaluation of weak growth stages with emphasize on germination and early growth of seedlings.*

WP 2.1 Sink/source dynamics of biomass dry weight and carbohydrates in underground plant parts.

We will study the influence of cutting, or soil tillage, on the ability of the three *Rumex* species to invade and dominate grassland systems. The experiment will clarify the relationship between *Rumex* spp. developmental stages and sink/source dynamics of biomass dry weight and carbohydrates in underground plant parts, and thereby determine the compensation point, at which there is a minimum of food reserves in the underground plant parts of these species. The compensation point of plant species is influenced by shoot competition and the experiment will be carried out both with (grass species) and without competing plants. In order to study the reaction of different times of moving on growth of *Rumex* spp. the following year, the experiment will include a parallel series of plots in which underground plant parts is not harvested. The study will be carried out as a semi-field experiment with wooden frames around an area of $1m^2$. To strengthen our knowledge about sink or source dynamic of carbohydrates in Rumex spp., ^{14}C technique will be used for measuring carbohydrate translocation upward or downward, as well as the determination of the phenological stadium of the shift of translocation direction. The experiment will be carried out in a growth chamber.

WP 2.2 Dynamics of seed germination and regeneration of shoots from root parts of docks

There is a general agreement that seed germination of *R. crispus* and *R. obtusifolius* is promoted by light and alternating temperatures. In this WP we will study whether *R. longifolius* acts the same way. Experiments will be carried out in growth chamber / germination laboratories facilities, as well as in the field. The study will include germination dynamics of all the three docks species.

Some reports conclude that regeneration from root parts of *R. obtusifolius* and *R. crispus* mainly occur during early spring and one essential question is whether this is true also under Norwegian conditions with short spring and whether *R. longifolius* behave similar as the other two species. This experiment, including all the three dock species as well as different plant developmental stages, will be carried out both in field and in growth chamber.

Sub objective 3

Evaluate potential for biological control of Rumex spp by natural enemies occurring in Norway.

WP 3.1 Collection and testing of natural enemies

Aerial parts of mature plants with leaf spots or necroses from infections will be collected in the *Rumex* populations. Samples of leaf and stem pieces will be incubated on wet filter paper or on water agar. Spores or mycelium germinating in the plant residues will be isolated and cultured under sterile conditions on a suitable medium. The organism will be identified and stored and will be available in the collection of isolates for assays and further investigation. Potential as parasite on *Rumex* will be evaluated on detached leaves. Suspensions of the most aggressive isolates will be applied on intact plants in a spray bench and if promising also evaluated in field trials. Spores of rust fungi will be collected and bulked up on living plant material

Herbivores will be sampled by hand during the growing season. Abundance and damage caused (and to which part of the plant) will be noted. They will be brought back to the lab and reared through one whole generation on the host species, other common *Rumex* and *Polygonum* species and rhubarb. Insects will be identified using standard keys.
During the project, a decision will be made on 'promising' insects, i.e. those that are abundant, easy to rear and seem to cause significant damage in the field. These will be subjected to a preliminary host-range testing and also laboratory studies to determine their effectiveness in controlling different *Rumex* sps, at different stages of their life cycles (germinating seedling, developing plant, seed-producing plant)

WP 3.2 The combined effect of plant pathogens and herbivore insects will be evaluated at different growth stages of *Rumex*. The trials will start with model trials in controlled climate and semi field trials. If interesting results are obtained trials under practical field conditions will be carried out.

Sub objective 4
Optimize control of docks in organic farming by integrating possible control measures and grassland management practises of grass-legume leys to promote competitive ability against taller Rumex spp.

WP 4.1 Full-factorial field experiments with key-factors for *Rumex* development
This WP will include field studies on the population dynamics during a four year period. The experiment design will be carried out as a full-factorial, including key-factors, which also separately may significantly influence dock behaviour. The first factor, date of grassland establishment, may be important for preventing /decreasing the flush of seedlings from seeds as well as shoots from root fragments. The second factor, black fallow, will act both as a false seedbed and for decreasing food reserves in underground plant parts. Both through the combination of an optimal date of sowing and a black fallow period, the number of seedlings and shoots may be decreased. The two latter factors are on the other hand influencing docks competitive ability. We believe that the combination of all the experimental factors during years will give us new and important knowledge for better advising organic grassland farmers in the future. We have not added cutting as a factor in to this experiment because numerous studies have concluded that cutting must be done very frequently for controlling docks species, which is difficult in an applied point of view. Preventive factors are therefore highlighted in this experiment.

In this factorial experiment we will add the following factors and levels with focus on grassland renewing:
1. Date of sowing: a) spring vs. b) mid-summer (after harvesting once)
2. Black fallow: a) no black fallow vs. b) black fallow during 1 month
3. Competition: a) 'normal' seed mixture vs. b) *Dactylis glomerata*
4. Fertilization: a) 'low' vs. b) 'high'

Number of treatments: $2^4 = 16$.

The experiment will be carried out with 4 replications, all together 64 plots.
The field experimental series will be located at 3 places, Valdres (inland, mountain area), Jæren (south west coast) and Troms (northern Norway). The *Rumex* infestation in each plot will be assessed (start characterization) in the autumn 2006, before initiating the experiment in spring 2007.

WP 4.2 Field experiment for optimizing the soil tillage effect on docks
In these experiment(s) we will address the black fallow/soil tillage period in more detail for improving the effect on docks. The experiment will include factors:
1. Sowing time of the ley
2. Pre-treatment, shallow ploughing or rototillling, before ploughing
3. Length of soil tillage / black fallow period
4. Frequency of harrowing during black fallow period

The experiment will carried out as a field experiments with 4 replications, and will be located at one place. Start characterization of dock distribution will be carried out.

5. **Project organisation and management**

The project is collaboration between different divisions of Bioforsk, and farmers group represented by Valdres KvalitetBA, associations of organic farmers in Rogaland and Møre og Romsdal county.

Bioforsk Plant Health and Plant Protection is the coordinator of the project and will be responsible for research design of the experiments. Most of the trial carried out in laboratory and climate regulated conditions including the PCR- work will take place here. Plant Health and Plant Protection has laboratories and experience to facilitate isolation and culturing of organism for biological control. The coordinator is responsible for organizing annual project meetings for the partners and the involved farmers.

Bioforsk Arctic Agriculture and Land Use will carry out field trials in Northern Norway, and ensure contact with farmers group in the actual area. Together with The University of Tromsø they run one of three phytotron installations in Norway, with excellent facilities of running different growth conditions. They will also take care of the field surveys in north.

Bioforsk Arable Crops Løken will carry out field trials in mountains area together with farmers associated in Valders Kvalitet BA.

Rogaland County in southern Norway is the most important meet and dairy producing area in Norway. The local Agricultural Extension Service and the Organic farmers association will together with farmers groups carry out surveys and field trials in an effort to increase the amount of organic farmed meat and dairy product.

6. **International cooperation**

The University of Reading, UK.
Dr. Paul Hatcher at the University of Reading has long experience in studies on biological control. Biological control by use of one agent rarely has proved successful and the cooperation with Paul Hatcher is motivated by his progress with combining native pathogenic fungus and herbivore insects.

As a part of the project we will engage master students at the University of Reading, UK, and the Norwegian University of Life Sciences, Ås.

7. **Progress plan - milestones**

ACTIVITY:	2006		2007				2008				2009				2010			
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
„Kick off" meeting between all partners	x																	
WP 1.1 *Rumex infestation and management ….*	x			x	x			x	x			x	x		x			
WP 1.2 *Competition and soil K….*								x	x	x		x	x	x	x			
WP 2.1 *Compensation point….*				x	x			x	x			x	x	x				
WP 2.2 *Germination and shoot dynamics…*				x	x			x	x									
WP 3.1 *Natural enemies; collection and testing…*	x			x	x	x		x	x	x		x	x	x	x	x	x	
WP 3.2 *Natural enemies: evaluation*								x	x	x		x	x	x	x		x	
WP 4.1 *Full factor field experiment: Rumex dynamics*	x			x	x			x	x				x	x		x	x	
WP 4.2 *Optimized soil tillage for Rumex control*								x	x				x	x				
Annual project meeting,			x				x				x					x		
Publication national and international journals, meeting etc.			x				x				x			x	x	x	x	x
Reports		X			x					x				x				x

8. Costs incurred by each research performing partner

Bioforsk	**2006**	**2007**	**2008**	**2009**	**2010**	***Total***
Personnell costs and indirect costs	210	775	825	800	610	*3 220*
Equipment						*0*
Other operating costs	100	230	370	345	115	*1 160*
Total	**310**	**1 005**	**1 195**	**1 145**	**725**	***4 380***

The costs incurred by The University of Reading are included in the sums for Bioforsk.

9. Financial contribution by partner (Finansiering per partner)

	2006	**2 007**	**2 008**	**2 009**	**2 010**	***TOTAL***
Bioforsk	50	100	100	100	50	*400*
Fondet for forskningsavgifter/avtalepartene	78	272	329	314	203	*1 194*
Norwegian Research Council	182	634	767	732	473	*2 786*
Funding in total	**310**	**1 005**	**1 195**	**1 145**	**725**	**4 380**

The funding from the Norwegian Research Council/'Fondet for forskningsavgifter / avtalepartene' is divided by 70% and 30%, respectively.

PART 2: Exploitation of results

10. Relevance for knowledge-building areas

This project is directed towards a specific call for proposals regarding organic production and marketing and is aiming at the very important meat and dairy sector.

Its most important contribution is removal of a major obstacle for farmers to convert to and prevail in organic food production. Without reliable supply, all market and branding initiative of organic products will be in vain.

The research results from this project will be very important for research based teaching at the Norwegian University of Life Science. Lars Olav Brandsæter is responsible for and main lecturer in weed science and the direct link to the students ensure that new knowledge is efficiently communicated and that new methods will be implemented in practical farming. Master students will be directly engaged in the project. An added value is the cooperation with University of Reading, School of Biological Science.

11. Importance to Norwegian industry

For the time being there are many initiatives for production of food with local character. Valdres KvalitetBA is one example (see attached). Branding to make the products visible for the market is a paramount part of this work. An element of the branding prescriptions is very often sustainable production and utilisation of local resources. That imply in many cases organic farming or not to use chemical pesticide in the production. Stable and high quality fodder production in grass-clover leys and pastures with no use of herbicide makes the dock infestation a real challenge. More and more farmers expect and experience that dock infestation is limiting their ability to reach their production goals.

The potential for added value due to the results from the project is high because through new methods in *Rumex* control mismatch between sufficient organic farmed grass-clover forage and production goal for organic and/or branded food products will be avoided.

An expected increase in demand for organic produced milk and meat, also as results from planned campaigns in 2006, (http://odin.dep.no/lmd/norsk/tema/okologisk/nyheter/049051-211767/dok-bn.html) without stable supply of Norwegian products will open up for import.

12. Relevance for call for proposals and programmes

Relevance for call for proposal:
Production adapted to processing and market, with focus on the whole value chain.
The project aims to enable the organic farmers to have a stable supply of meat and dairy products for the processing industry for many years. Also farmers that deliver products according to specified guideline (brands) where pesticide application is not accepted will benefit from the expected result of the project.

Effect for society like biodiversity, health, use of recourses and pollution
Biodiversity is enhanced on organic farms (få Helge til å skrive litt om dette). Initiative taken to production based on own local produced forage is a good way to utilize local resources.

13. Environmental impact

The results from this project will have a positive effect on the environment because more farmers will be motivated to convert to organic farming due to less fear of loosing control of *Rumex* infestation. Also the expected new methods of *Rumex* control will be relevant for conventional farmers and less herbicide will be applied.

14. Information and dissemination of results

The project shall result in at least five papers in international journals.
Target group: International scientists
Relevant journals: Weed Research, Biological Control, Canadian Journal of Plant Science, Weed Science

Presentations and posters at international conferences and workshops.
Target group: International scientists
Actual workshops and conferences are: 14th European Weed Research Society (EWRS) Symposium, June 2007, European Grassland Congress, World Grassland Congress,

Relevant results exploited by end-users.
Target group: Extension service and farmers

- Presentation on relevant national conferences
- Papers in relevant periodicals
- The project will have a special area on the web site of Bioforsk that will be updated frequently on activities and results.
- At the beginning of the project period, meetings involving the researchers, extension service the farmers will be held.
- The project team including the active partners in the project will assist the farmers in implementing promising result to spread the gained knowledge.

References

Andersson, P-A. 2005. Skräppa – ett växande problem i ekologisk odling. Delårsredovisning för 2005. http://fou.sjv.se/fou/default.lasso

Cavers, P.B. & J.L. Harper 1964. Biological flora of the British Isles. *R. obusifolius* L. and *R. Crispus* L. Journal of Ecology 52: 737-766.

Charudattan, R. 2001. Biological control of weeds by means of plant pathogen: significance for integrated weed management in modern agro-ecology. BioControl 46: 229-260.

Courtney, A.D. 1985. Impact and control of docks in grassland. In weeds, Pests, and Diseases of Grassland and Herbage Legumes (ed. JS Brockman), 120-127. British Crop Protection Council, Croydon, UK.

Dierauer, H.-U. & H. Stöppler-Zimmer 1994. Unkrautregulierung ohne Chemie. Verlag Eugen ulmer, Stuttgart, Germany.

Eekeren, N. van & P.S. Jansonius 2005. Ridderzuring beheersen – Stand van zaken in onderzoek en praktijk (English summary). Luis Bolk Instituut, Driebergen NL. 55 pp.

Ellenberg, H. 1986. Vegetation Mitteleuropas mit den alpen, 4th edn. Verlag Eugen Ulmer, Stuttgart, Germany.

Fykse, H. 1986. Experiments with *Rumex* species Growth and regeneration. Scientific reports of The Agricultural University of Norway 65 (25) (Reprint no.197 from The Norwegian Plant Protection Institute Department of Herbology) 11pp.

Galler, J. 1989. Grünlandverunkkrautung. Ursachen, Vorbeugung, Bekämpfung. Leopald Stocker Verlag, Graz, Austria.

Hatcher, P. E. 1996. The effect of insect–fungus interactions on the autumn growth and overwintering of *Rumex crispus* and *R. obtusifolius* seedlings. *Journal of Ecology* 84, 101–109.

Hatcher, P.E. & B. Melander 2003. Combining physical, cultural and biologicaø methods: prospects for integrated non-chemical weed management strategies. Weed Research 43: 303-322.

Hatcher, P. E. & N. D. Paul 2000. Beetle grazing reduces natural infection of *Rumex obtusifolius* by fungal pathogens. *New Phytologist* 146, 325–333.

Hatcher, P. E., N. D. Paul, P. G. Ayres & J. B. Whittaker 1994a. Interactions between *Rumex* spp., herbivores and a rust fungus: *Gastrophysa viridula* grazing reduces subsequent infection by *Uromyces rumicis*. *Functional Ecology* 8**,** 265–272.

Hatcher, P. E., N. D. Paul, P. G. Ayres & J. B. Whittaker 1994b. The effect of an insect herbivore and a rust fungus individually, and combined in sequence, on the growth of two *Rumex* species. *New Phytologist* 128**,** 71–78.

Hatcher, P. E., N. D. Paul, P. G. Ayres & J. B. Whittaker 1997. Added soil nitrogen does not allow *Rumex obtusifolius* to escape the effects of insect–fungus interactions. *Journal of Applied Ecology* 34**,** 88–100.

Haugland E., 1993. Competition between an established grass sward and seedlings of Rumex longifolius DC. and Taraxacum officinale (Web.) Marss. Norwegian Journal of Agricultural Sciences 7, 409-420.

Healy, A. 1953. Control of Docks. New Zealand Journal of Science and Technology, Section A 34: 473-475.

Holm, C. & H. Korpelainen 1999. Geographical differentiation of *Rumex longifolius*. Nordic Journal of Botany 19 (1): 15-22.

Humphreys, J., T. Jansen, N. Culleton, FS. Machnaeidhe & T. Storey 1999. Soil potassium supply and *Rumex obtusifolius* and *Rumex crispus* abundance in silage and grazed grassland swards. Weed Research, 39, 1-13.

Håkansson, S. 2003. Weeds and weed management on arable land. An ecological approach. CABI Publishing, Wallingford, UK. 274 p.

Jin D.C., J.Y. Park, J.W. Bang JW & Y Hur 2004. Isolation and characterization of male-specific DNAs by genomic AFLP from the dioecious plant *Rumex acetosa* L. Korean Journal of Genetics 26: 171-178.

Keary, I. P. & P.E. Hatcher 2004. Combining competition from *Lolium perenne* and an insect–fungus combination to control *Rumex obtusifolius* seedlings. *Weed Research* 44, 33–41.

Lid, J. 1979. Norsk og svensk flora. Det norske samlaget, Oslo, 808 pp.

Marten, G.C., C.C. Sheaffer & D.L. Wyse 1987. Forage nutritive value and palatability of perennial weeds. Agronomy Journal 79: 980-986.

Moore, J.P., J.E. Taylor, N.D. Paul & J.B. Whittaker 2003. The use of clip cages to restrain insects reduces leaf expansion systemically in *Rumex obtusifolius*. Ecological Entomology 28: 239-242.

Müller-Schärer, H. & P.C. Scheepens 1997. Biological control of weeds in crops: a coordinated European research Programme (COST-816). Integrated Pest Management Reviews 2, 45-50.
Navajas-Perez R, R. de la Herran, G.L. Gonzalez, M. Jamilena, R. Lozano, C.R. Rejon, M.R. Rejon & M.A. Garrido-Ramos MA 2005. The evolution of reproductive systems and sex-determining mechanisms within *Rumex* (Polygonaceae) inferred from nuclear and chloroplastidial sequence data. Mol. Biol. Evol. 22: 1929-1939.
Obendorfer, E. 1990. Pflanzensoziologishe Exkursionsflora, 6th edn. Verlag Eugen Ulmer, Stuttgart, Germany.
Oswald, A.K. & R.J. Haggar 1983. The effects of *Rumex obtusifolius* on the seasonal yield of two mainly perennial ryegrass swards, Grass and Forage Science 38: 187-191.
Pino, J., R.J.Haggar, F.X.Sans, R.M.Massales, R.N.S.Hamilton & R.N.Sackville Hamilton 1995. Clonal growth and fragment regeneration of *R. obtusifolius* L. Weed Research 35: 141-148.
Pötsch, E.M. 2003. Möglichkeiten der mechanisch/biologischen Ampferbekämpfung. Landbauerforschnung Völkenrode 255: 63-68.
Roberts, E.H. & S. Totterdell 1981. Seed dormancy in Rumex species in response to environmental factors: review article. Plant, Cell and Environment 4: 97-106.
Stehlik I 2002. Glacial history of the alpine herb *Rumex nivalis* (Polygonaceae): A comparison of common phylogeographic methods with nested clade analysis. American Journal of Botany 89: 2007-2016.
Zaller, J.G. 2004a. Competitive ability of *R. obtusifolius* against native grass species, above and belowground allocation of biomass and nutrients. *Journal of Plant Diseases and Protection* 19, 345-351.
Zaller, J.G. 2004b. Ecology and non-chemical control of *R. crispus and R. obtusifolius* (Polygonaceae): a review. Weed Research 44: 414-432
Weaver, S.E. & P.B. Cavers 1979a. Dynamics of seed populations of *R. crispus* and *R. obtusifolius* (Polygonaceae) in disturbed and undisturbed soil. Journal of Applied Ecology 16: 909-917.
Weaver, S.E. & P.B. Cavers 1979b. The effects of date of emergence and emergence order on seedling survival rates in *R. crispus* and *R. obtusifolius*. Canadian Journal of Botany 57: 730-738.
White TJ, T. Bruns, S. Lee & J. Taylor 1990. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ and White TJ, eds. *PCR protocols. A guide to methods and applications.* New York: Academic Press, 315-322.