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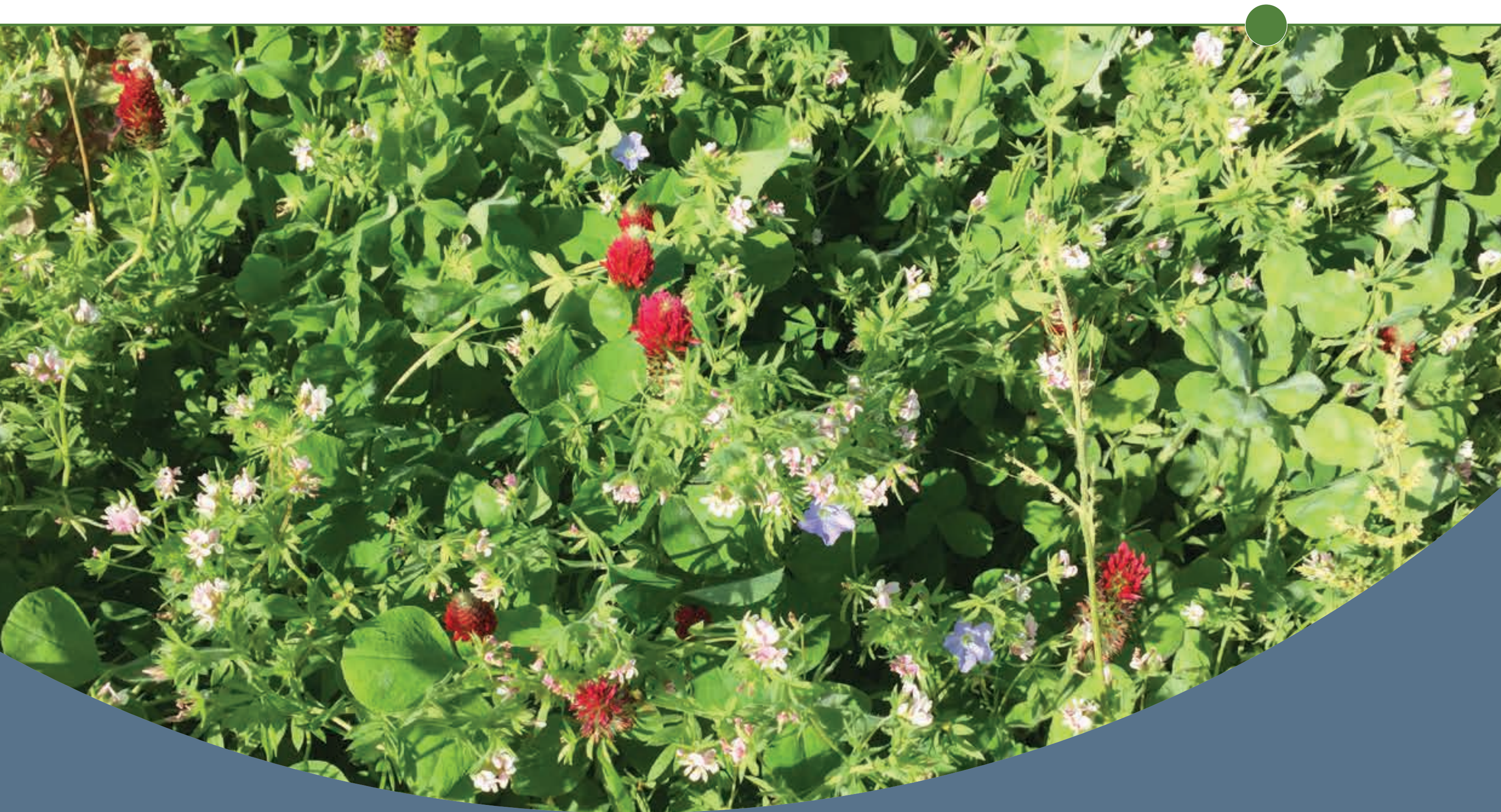

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with contributions from Andrew G. Howe, Marian Ørgaard &
Nané Køllgaard Pedersen

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Foreword

This report summarises empirically substantiated findings regarding the use of herbaceous cover crops as a weed management technique when establishing woody plantings. Based on this, practical recommendations are given for the green sector in southern Sweden, Denmark and other temperate and hemi-boreal vegetation zones of southern Scandinavia and neighbouring countries. The most common cover crop species used successfully to control resident weeds when establishing woody plantings are also described. In Denmark, cover crops are generally called 'dækafgrøde' and in Sweden 'täckgröda'. The report is written in English to make it accessible beyond the main target group.

The report is a joint output from: a "Best Practice project" at the Faculty of Landscape Architecture, Horticulture and Crop Production Science, Swedish University of Agricultural Sciences, Alnarp and three projects at the Section for Landscape Architecture and Planning, University of Copenhagen: two Partner Landscape projects "Vedplantninger etableret med bunddækkende urter" and "Formidling og dataindsamling om bunddækkeurter i vedplantninger"; and an applied research project "Bæredygtig etablering af vedplantninger – dækafgrøders uudforskede potentiale" funded by Godfred Birkedal Hartmanns Familiefond.

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All photos and diagrams were produced by the authors, unless otherwise stated.

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State of the art – Extensive summary

The focus on ecosystem services and biodiversity has given herbaceous cover crops renewed and wider relevance as a weed management technique when establishing plantings of woody species. As an ecological management technique, cover crops provide an alternative to chemical and mechanical weed control. Cover crops also have the potential to add lushness and flowering, with associated experiential merits and biodiversity values.

In the Scandinavian countries and elsewhere, demands by the public to reduce the use of chemical weed control gained momentum during the late 1980s and early 1990s. This resulted in research on using and testing cover crops as an alternative weed management technique when establishing various types of woody plantations. The use of cover crops when establishing woody plantings has continued on a small scale and additional trials have successively been established across Europe, but systematic knowledge exchange and a review of the state of the art have been lacking. We therefore set out to review controlled trials examining the influence of cover crops on the survival and growth of young woody plants and comparing cover cropping to other weed management techniques.

The review included controlled trials from across Europe and a look at North American studies. Obviously, abiotic and biotic factors varied considerably between the trial areas. While this requires caution when comparing findings, it also strengthens the reliability of findings that remained consistent across the trials. In the following, we focus on these general patterns.

In research to date, cover crop effects on the survival and growth of woody plants have mainly been compared with chemical weed control and free development of resident vegetation (control treatment). Comparisons of cover crops with mechanical weeding and different kinds of synthetic and organic mulches/barriers have been surprisingly few.

A great diversity of species and species mixtures have been tested within individual trials and, not least, in different trials. In studies comparing cover crops and free development of resident weeds, woody plants are reported to have higher survival and growth in cover crop treatments in approximately half the total number of studies, while the other half report the opposite. Differences between these two treatments are seldom significant, however. This indicates that, while positive experiences have been found in controlled trials, the fundamental basis of using cover crops as a weed management technique in woody plantings is not yet fully established.

The clear majority of the cover crop species tested to date have been cultivars of native and non-native species used in conventional commercial agriculture/horticulture. However, wild flower mixtures are frequently mentioned in the literature as an innovative option, and have also shown positive results in tests. In light of the contemporary discourse on ecosystem services and biodiversity support, greater use of local wild flower mixtures as cover crops is relevant.

There is strong empirical evidence that establishment of woody plants is favoured significantly by 'conventional' horticultural weed management techniques that keep the soil *entirely* free from competing weeds, i.e. organic mulches, application of herbicides and intensive mechanical weeding. While this may come as no surprise, the current political and societal focus on cost-effective management practices and ecosystem service provision mean that these 'conventional' weed management techniques are not applicable on a large scale for public organisations in Scandinavia. On a large scale, only extensive mechanical weed management techniques or sowing of cover crops appear to be realistic alternatives to free development of resident weeds. Against this background, this review presents empirically substantiated information of relevance for contemporary weed management practice and professional perceptions.

Studies that are particularly relevant for contemporary professional practice and discourse are comparisons of mechanical weed control and cover crops. These repeatedly show higher survival and growth rates of woody species with mechanical weed control compared with cover crops, but the differences are rarely significant. This is probably because extensive mechanical weed control, e.g. with tractor-mounted aggregates, is of necessity restricted to weeds in the gaps between the plant rows, while leaving weeds in the immediate periphery of the woody plants. In the literature, mechanical weeding only results in significantly higher survival and growth of woody plants compared with a cover crop treatment when the soil is kept entirely clean by labour-intensive weeding (or the cover crop includes species known to be very strong competitors).

The limited number of studies in which mechanical weed control is compared to cover crops poses a major constraint to generalisation, and future research should include intensive and extensive mechanical weed management techniques for comparison with cover crops and free development of resident weeds. That said, the existing evidence base indicates that the choice between extensive mechanical weed management (e.g. tractor-mounted cultivator) and cover crops rarely is a question of jeopardising the survival and growth of the woody plants, but rather of balancing cost and benefits and the desired appearance of the planting, i.e. aesthetic considerations. An important exception is planting sites where there is a large population of rodents such as field voles and where herbaceous cover crops provide cover against predators, increasing rodent damage to the woody plants.

When establishing plantings of woody species, the choice of weed management technique is inevitably an act of balancing many aspects. Cover cropping offers a possibility especially when environmental sensitivity and a lush, but well-tended, appearance during the establishment phase are prioritised.

Cover crops as weed control in woody plantings – condensed guidelines

This review resulted in the development of guidelines on practical use of cover crops as a weed management technique when establishing woody plantings. The guidelines are targeted at practitioners and students in southern Sweden, Denmark and other temperate and hemi-boreal vegetation zones of southern Scandinavia and neighbouring countries. The guidelines are elaborated upon in Chapter 4 of this report and can be summarised as follows:

Cover crop composition:

- Few species possess all the phenologies and functional traits needed in a cover crop. This requires use of mixtures composed of species with rapid leaf areal development from seed, species with dense foliage and preferable also annual, biennial and perennial species.
- Danish experiences support the use of mixtures of two to five species, each selected to fulfil a specific role.
- Simple mixtures with a uniform character linking to agriculture and horticulture can provide a high degree of stewardship. However, more complex mixtures with native wild flower species can increase perceived naturalness.
- Cover crops generally have the potential to support biodiversity. However, caution is needed concerning inclusion of aggressive species (cultivars of native species as well as non-native species), as these can disperse and become a threat to local biodiversity.
- The contemporary discourse on ecosystem services and biodiversity conservation encourages use of cover crops composed of local wild flower species, despite the empirically substantiated knowledge base for such cover crops still being very limited.
- Cover crops often include legumes capable of fixing airborne nitrogen. However, nitrogen is only a limiting factor for tree growth on very poor sites. If legumes are used, annual/biennial legumes generally pose less competition to the woody plants, although the perennial *Lotus corniculatus* is a valuable exception.
- At exposed sites, tall growing species with strong stems and upright growth, like *Secale cereale*, can be included to provide wind shelter and related microclimate benefits for young woody plants.
- Cover crop species with dense foliage and species that have decumbent stems or vines often cling on to woody plants, and should thus not grow to more than two-thirds their height.
- Many cultivars (e.g. of *Trifolium* species) develop rather aggressively in height and biomass and often become too high and cling on to woody plants planted as bare-rooted individuals (often no more than 50-80 cm when planted). This justifies use of seeds harvested from wild seed sources, despite the added cost, or cultivars breed to be low if such are available.

Site preparation:

- Thorough soil preparation to ensure that the soil is free from weed propagules, especially of perennial weeds, is equally important for good establishment of the cover crop and the woody planting. Even the best cover crop cannot catch up with and suppress perennial weeds if they have a head start.
- Deep cultivation should at best be carried out at least one month prior to establishing the woody plants and/or sowing the cover crop, and should be followed by two or three shallow cultivations of the surface soil (just the top 5 cm) to subdue emerging weeds.

Sowing density and technique:

- Sowing density should be reduced to approximately one-third compared with the recommendations for cover crops for agricultural use. This will still give good coverage of the soil and reduce competition with the woody plants, as well as reducing the purchase cost of seeds.
- Sowing should be carried out when the soil surface is 'workable', but still moist. If rain is not forecast for the following week(s), irrigation can be used to support rapid germination of the seeds.
- After sowing, a shallow spring tine harrowing/racking or, at a minimum, a roller or cultipacker should be run over the soil to ensure good contact between seeds and soil.
- Smaller areas can easily be hand-sown. Hand-sowing is easier if the seeds are mixed with sand, sawdust or granules.
- If larger areas are to be sown with cover crops, sowing can possibly precede planting of the woody species. This would allow use of an agricultural seed drill. Pneumatic drills ensure that seeds of different size and weights are not separated during sowing.

Post-sowing management of cover crops:

- Emerging perennial weeds could be removed manually during the first season, in the same way as farmers walk their fields to pick *Avena fatua* before they disperse the seeds.
- Mowing of the cover crop should be avoided, as this shifts the competitive advantage in favour of grasses. However, trimming of edges facing e.g. paths can induce cues to care and perceived stewardship. Cutting a path through a woody planting with a lush cover crop can also induce 'cues to care' and enable people to experience the flowering close up.

1: Introduction

This report summarises empirical experiences concerning the use of herbaceous cover crops as a weed management technique when establishing woody plantings. The recent focus on ecosystem services and sustainable development has given herbaceous cover crops renewed and wider relevance as a potential economically, environmentally and socially sustainable technique for weed control (Balandier et al. 2009; Willoughby et al. 2009). Besides providing an ecological engineering alternative to chemical and mechanical weed control within the same or even lower budget frame, cover crops can also add lushness and flowering with associated experiential merits and forage and habitat for bees, bumblebees, butterflies and other pollinating insects (Kristensson 1991; Sørensen and Juul 1993). These ecosystem services are important in the city, in the rural hinterland and in the woods.

When establishing new woody plantings, the rapid development of very competitive resident herbaceous species (i.e. weeds) can compromise tree establishment and long-term development. On previously cropped land or following intensive site preparation, development of resident weeds generally follows a succession of plant species, dominated first by annual forbs and grasses, giving way to presumably more competitive perennial forbs and then perennial grasses (Van Sambeek and Garrett 2004). Grasses, particularly perennial grasses, are generally reported to be the most competitive species, at least relative to most tree species (Balandier et al. 2006).

Weeds can be controlled in various ways, e.g. by application of herbicides, mechanically (motorised and/or manual), by installing some form of synthetic or organic mulch/barrier and by sowing herbaceous cover crops, the focus of this report.

Cover crops and woody plantings

The purpose of using cover crops in combination with woody species is to reduce, or in the best case completely suppress, the resident population of weeds with species that are selected to:

- be less competitive towards the woody plants
- provide protection against climate hazards (e.g. frost)
- add lushness and aesthetic value, e.g. flowers
- add forage and habitat for biodiversity, e.g. pollinating insects.

Fig. 1. Use of cover crops is an ecological engineering alternative to chemical and mechanical weed control that can add lushness and flowering with associated experiential merits and forage and habitat for biodiversity. Top photo: New woody planting in the city district Ringkøbing K in Denmark, where a 'traditional' cover crop mixture of Linum usitatissimum, Lotus corniculatus, Ornithopus sativus, Sanguisorba minor and Trifolium incarnatum has just been sown, 6 June 2016. Bottom photo: Same site, 23 May 2017. The cover crop is well established and suppressing resident weeds, and Trifolium incarnatum and Ornithopus sativus are flowering intensively. Photos: Nané Køllgaard Pedersen and Anders Busse Nielsen.

Fig. 2. Cover crops can be designed to flower from late spring all through to autumn. These photos show a cover crop in the city district Sletten, Holstebro, Denmark, in early summer 2003 (top) and in mid-summer 2003 (bottom). Photos: Carl Aage Sørensen.

Traditional uses of cover crops

Cover crops have a long tradition of use in agriculture, horticulture and environmental engineering. Cover crops have generally been selected from among cultivars of herbaceous species that have rapid development and dense coverage of the soil. Cover crops are used as annual or short-rotation vegetative ground cover to impede the development of resident weeds; protect against soil erosion; reduce nutrient leaching; support nutrient cycling and management; improve the soil; conserve microclimates and water; support beneficial insects in integrated pest management; and as forage and habitat for different mammals and insects as part of conservation and game management (Reeves 1994; Malik et al. 2000; Dabney et al. 2001; Hartwig and Ammon 2002; Delgado et al. 2006; Miller et al. 2006; den Hollander et al 2007a; Sirrine et al. 2008). However, when establishing woody plantings, cover crops can also provide undesirable cover and habitat for rodents such as field voles, increasing their damage to the woody plants (Thompson 1965; Merwin et al. 1999; Curtis et al. 2002; Wiman et al. 2009). For larger browsers, some studies suggest that cover crops act as an alternative fodder for larger browser, and can be used in combination with other management actions to reduce browsing damage (Miller et al. 2006).

Agroforestry as reference

Cover crops also exert competition with young woody plants, which may negatively impact their survival and growth. Agroforestry, i.e. the practice of combining trees and herbaceous crops, can provide some lessons about the use of cover crops when establishing woody plantings. A basic concept in agroforestry is root complementarity, i.e. the root systems of herbaceous crops and trees, which have different growth forms, inhabit different soil layers, leading to complementarity in nutrient and water resources (Schroth 1998). Some species can even provide facilitation effects, e.g. increased topsoil water availability through hydraulically lifting soil water through a deeper-reaching root system (Emerman and Dawson 1996). Another example of facilitation is legumes fixing airborne nitrogen. Unless heavily fertilised, forage legumes obtain on average about 75% of their nitrogen through the fixation process (Van Sambeek and Garrett 2004). When they decompose and organic nitrogen is converted to ammonia or nitrate, this nitrogen becomes available to other plants at the site, e.g. trees.

Root exploration of an already occupied soil volume induces competition, and not complementarity. The topic of root complementary therefore also relates to rooting speed, where the root development of herbaceous species generally exceeds that of woody species. In agroforestry, the herbaceous crops are normally introduced after the trees (Schroth, 1998), meaning that the trees have time to develop deep root systems. In contrast, when cover crops are used as weed control when establishing woody plantations, the trees and cover crops are established in parallel or shortly after each other, which imposes root competition in the upper soil volume. Thus, while agroforestry often focuses on promoting the herbaceous crop in relation to the trees (Schroth 1998), afforestation and other woody establishment projects might face the opposite concern, i.e. an overly vigorous cover crop that reduces tree survival and growth (e.g. Kristensson 1991; Adiele and Volk 2013; Albertsson et al. 2016).

The Scandinavian context

In the Scandinavian countries and elsewhere, public demand to reduce the use of chemical weed control gained momentum during the late 1980s and early 1990s. This resulted in research on use of cover crops as an alternative weed management technique when establishing various types of woody plantations (e.g. Kjærbølling 1995; Willoughby et al. 2009). Cover crops were used in afforestation, when establishing woody plantings in urban green spaces and shelterbelt plantings between arable fields and along infrastructure. Alongside the ecological engineering merits, the use of herbaceous cover crops is also motivated by the biodiversity support and experiential values their flowering and lush folia add to young woody plantings, i.e. by ecological-aesthetic arguments (e.g. Kristensson 1991; Sørensen and Juul 1993; Nielsen and Jensen 2007; Wiström and Pålsson 2010). However, most of the experiences from the 1980s and 1990 is restricted to qualitative studies and practical observations, while only a few controlled trials are reported.

Objectives

The relatively short history and fragmented empirical knowledge base may explain the ongoing discussions and uncertainty concerning the pros and cons of cover crops as a weed management technique when establishing woody plantings (e.g. Willoughby et al. 2009). Many see merits in cover crops, but also fear jeopardising the survival and growth of the young woody plants. Others question whether cover crops can really suppress and control weeds, without replacing competition by weeds with competition by the cover crop. After all, the cover crop is the means, but the success of the companion woody plants is the aim. The use of cover crops when establishing woody plantings has been tested at a small scale in recent decades and additional trials have been established across Europe over time, but systematic knowledge exchange and a review of the state of the art are still lacking. We therefore set out to review controlled trials in which the influence of cover crops on the survival and growth of woody plants has been tested and compared with other weed management techniques.

Fig 3. Polyommatus icarus foraging on Linum usitatissimum. Photo: Anders Busse Nielsen.

Specific objectives were to:

- Identify overall patterns concerning the influence of cover crops on the survival and growth of woody plants compared with other weed management techniques.
- Provide guidance for practical use of cover crops as a weed management technique when establishing woody plantings, in particular for the site conditions and management aims commonly found in southern Sweden, Denmark and other temperate and hemi-boreal vegetation zones in southern Scandinavia and neighbouring countries.
- Describe the phenological characteristics and traits of the cover crop species that have been most commonly used in southern Scandinavia.

2: Methodology used in the review

Search strategy

This review focused on controlled trials across Europe, with an outlook at North American studies, in which the influence of cover crops on the survival and growth of woody plants has been tested and compared with that of other weed control treatments. However, studies on e.g. agroforestry and intercropping in orchards where trees are well established when the cover crop/herbaceous vegetation is introduced were beyond the scope of the review.

Based on the language skills of the authors, studies reported in English or a Scandinavian language was included. A literature search was conducted in winter 2016/2017 in the major scientific database Scopus. The search was performed using the following keyword combinations: "cover crop" AND tree (339), "cover crop" AND forest (171), "cover crop" AND afforestation (9) and "cover crop" AND restoration (81). Based on title and abstract, relevant articles were selected for the full review.

When investigating and summarising a topic, serendipitous discoveries often prove important, such as finding a relevant paper when searching for something else or through examining the list of references in identified papers. Hence, we widened the scope beyond the search protocol by examining references cited by the papers identified in the primary search, an approach known as 'snowballing'. After the search, we also added relevant publications from our personal reference database, which mainly describe experiences from the Scandinavian countries reported in the native language and thus not identified through the search in Scopus.

Categorisation of weed management techniques

Weed management aims to reduce the negative effect of resident weeds on the crop (target species) using different techniques and systems where cost, risk and benefits of different aspects are balanced against each other. For the present review, the weed management techniques identified were grouped as follows:

- Chemical = Chemical weed control (herbicides) to maintain bare ground between the planted/sown trees. For studies where several different chemical treatments were tested, only that with the most positive impact on tree growth/survival was included.
- Organic mulch = Decomposable material used as ground cover, e.g. compost, wood chips, herbaceous biomass (hay, straw etc.)
- Synthetic mulch = Barriers of plastic film (opaque polyethylene) or landscape fabrics (woven polypropylene)
- Mechanical = Bare ground control using mechanical methods, including both motorised and manual scalping (i.e. cutting weeds off at or below ground level) or cultivation (i.e. uprooting and burying weeds).

- Mowing = Mowing weeds to reduce their seed production and evapotranspiration
- Cover crop = Herbaceous crop sown to suppress resident weeds.
- Grass = Sowing grass or grass mixtures, mostly used as a ‘control’ against which other treatments are compared.
- Free = Soil around the planted trees is left for free development of resident weeds. When included, this treatment is normally used as a ‘control’ against which other treatments are compared.

Based on e.g. den Hollander et al. (2007b) and Bastiaans et al. (2008) three main aspects of weed management can be distinguish: i) reducing available propagules (seeds and roots) of weeds; ii) preventing germination or emergence of weeds; and iii) reducing the competitive ability of weed seedlings. Table 1 provides an overview of how different techniques relate to these three aspects of weed management. In the table, the aspect of ‘preventing germination or emergence of weeds’ is split into preventing/reducing seed germination and preventing/reducing vegetative regrowth of perennial species from rhizomes (e.g. *Aegopodium podagraria* or *Elytrigia repens*) taproots (*Taraxacum* spp. or *Rumex spp.*), root buds (e.g. *Cirsium arvense*) etc.

Table 1. Matrix showing how individual weed management techniques (vertical columns) support different aspects of weed management (horizontal rows).

	Tilling/ploughing [1]	Chemical	Synthetic mulch	Organic mulch	Mechanical	Cover crop	Grass[2]	Free[2]
Reduce abundance of propagules of weeds	■							
Prevent generative germination of weeds (from seeds)	■		■	■	■	■	■	
Prevent vegetative re-growth of perennial weeds (from roots)	■	■	■	■	■	■	■	
Reduce the competitive ability of germinated weeds		■			■	■	■	

[1]Only feasible as a pre crop establishment treatment and thus not included in the trials reviewed here.

[2] Mostly used as a control for comparison with other treatments.

Data extraction and analysis

For each study reviewed, data on the response of woody plants to treatments were extracted and ordered into two classes: survival and growth. ‘Growth’ involved different measurements of size increment, such as height, root collar or breast height diameter or whole plant measurements. In studies including more than one growth measurement, only those that were statistically significant were included in the review. For each study, the effect of different weed management techniques on survival and growth of woody species was ranked, beginning with the most positive impact and ending with the least positive. However, since most studies reviewed included repeated measurements (e.g. after first, second and third growth season), only the latest measurement was included in the ranking, to minimise responses to atypical climatic conditions.

3: The empirical knowledge base

Characteristics of European trials with cover crops and woody plants

In Europe, the effect of herbaceous cover crop on establishment of woody plants has been studied in controlled trials located far apart geographically, with Vilppula, Finland, being the most northern and Orvieto, Italy, the most southern (Tables 2 and 3). Temperature sum, annual rainfall, soil type and legacy of former land use obviously vary between the trial areas. Furthermore, cover crops have been sown with different techniques, at different densities and during different seasons of the year. The timing of introducing the cover crop relative to the woody plants has also varied, from sowing prior to the planting of woody species to sowing directly following planting of woody species or one year later.

Species with varying phenologies and traits have been tested and compared in different studies (Tables 2 and 3). The woody species include trees and shrubs, pioneer and climax species, broadleaved species and conifers. The cover crops vary from monocultures (e.g. Kristensson 1991; Paris 1995; Hànninen 1998; Willoughby et al. 2004) to rich mixtures (Willoughby and McConald 1999; Dassot and Collet 2015). Most of the cover crops tested have been monocultures of annual, biannual and/or perennial cultivars of 'traditional' cover crop species, legumes being most frequent. Other cover crops have been mixtures of wild flowers motivated by the increased conservation value (e.g. Willoughby and McConald 1999; Dassot and Collet 2015) or ornamental species (Willoughby et al. 2004) not traditionally used as cover crops. Others studies have included species normally regarded as aggressive weeds, e.g. *Aegopodium podagraria* (Kjærbølling 1995) or perennial grasses, e.g. *Festuca ovina* and *Festuca longifolia* (Willoughby 1999) or *Lolium perenne* (Hels et al. 2002).

Table 2. Summary of controlled trials across Europe examining the effect of cover crops on survival of woody plants compared with other weed management techniques. For each study, the effect of the different weed management techniques is ranked, beginning from the left, in order of the most positive impact followed by the second most positive and so forth: > indicates significant difference between treatments. Annual rainfall data were extracted from the papers and, if measured during the experiment, pooled to a mean. Where data were missing, national databases were used to extract data on mean annual precipitation for the region.

Reference	**Woody species**	**Cover crop species**
Albertsson et al., 2016	*Salix Tordis/Gudrun*	*Trifolium repens & Trifolium resupinatum*
Hytönen & Jylhä, 2005	*Betula pendula*	*Trifolium repens*
Jylhä & Hytönen, 2006	*Pinus sylvestris*	*Trifolium repens*
Jylhä & Hytönen, 2006	*Picea abies*	*Trifolium repens*
Kjaerbolling,1995	*Quercus robur*	*Aegopodium podagraria, Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Medicago sativa, Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Kjaerbolling,1995	*Quercus robur*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Quercus robur*	*Lotus corniculatus & Cichorium intybus*
Kjaerbolling,1995	*Fagus sylvatica*	*Aegopodium podagraria & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Medicago sativa & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Kjaerbolling,1995	*Fagus sylvatica*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Fagus sylvatica*	*Lotus corniculatus & Cichorium intybus*
Kristensson, 1991	*Species rich mixture*	*Trifolium repens*
Kristensson, 1991	*Species rich mixture*	*Trifolium repens*
Sæbø et al., 2009	*Abies nordmanniana*	*Trifolium repens*
Willoughby & McDonald, 1999	*P. nigra, A. peseudo.*	*Meadow mixture*
Willoughby & McDonald, 1999	*P. nigra, A. peseudo.*	*Brassica oleracea*
Willoughby, 1999	*Fraxinus excelsior*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Fraxinus excelsior*	*Prunella vulgaris & Plantago lanceolata*
Willoughby, 1999	*Fraxinus excelsior*	*Trifolium repens*
Willoughby, 1999	*Fraxinus excelsior*	*Hordeum spp.*
Willoughby, 1999	*Fraxinus excelsior*	*Brassica oleracea*
Willoughby, 1999	*Fraxinus excelsior*	*Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Fraxinus excelsior*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata*
Willoughby, 1999	*Fraxinus excelsior*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata & Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Fraxinus excelsior*	*Galium saxatile & Prunella vulgaris*
Willoughby, 1999	*Fraxinus excelsior*	*Hypericum androsaemum*
Willoughby, 1999	*Fraxinus excelsior*	*Lupinus arboreus & Lathyrus sylvestris*
Willoughby, 1999	*Pseudotsuga menziesii*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Pseudotsuga menziesii*	*Prunella vulgaris & Plantago lanceolata*
Willoughby, 1999	*Pseudotsuga menziesii*	*Trifolium repens*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hordeum spp.*
Willoughby, 1999	*Pseudotsuga menziesii*	*Brassica oleracea*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Pseudotsuga menziesii*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata*
Willoughby, 1999	*Pseudotsuga menziesii*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata & Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Pseudotsuga menziesii*	*Galium saxatile & Prunella vulgaris*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hypericum androsaemum*
Willoughby, 1999	*Pseudotsuga menziesii*	*Lupinus arboreus & Lathyrus sylvestris*
Willoughby, 1999	*Fraxinus excelsior*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Fraxinus excelsior*	*Prunella vulgaris & Plantago lanceolata*
Willoughby, 1999	*Fraxinus excelsior*	*Trifolium repens*
Willoughby, 1999	*Fraxinus excelsior*	*Brassica oleracea*

							Rain mm	pH	Soil	City	Country
Mech. chem.		Mech.	>	Cover crop			630	7.4	Clay-Silty	Alnarp	Sweden
Mulch		Chem.	>	Free		Cover crop	620	*	Mineral soil	Vilppula	Finland
Chem. Free		Mulch	>	Cover crop			620	*	Mineral soil	Vilppula	Finland
Free Chem.		Mulch		Cover crop			620	*	Mineral soil	Vilppula	Finland
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978		Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978		Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978		Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978		Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978		Sandy	Lovbakke	Denmark
		Mech.		Delayed cover crop	>	Cover crop	600	*	Loam	Eslöv	Sweden
		Mech.		Delayed cover crop	>	Cover crop	600	*	Loam	Landskrona	Sweden
Chem.		Mech.		Cover crop		Free	1365	*	Mineral soil	Saerhim	Norway
		Chem.		Cover crop		Free	750	7	Silty	Winchster	England
		Chem.		Cover crop		Free	750	7	Silty	Winchster	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
Chem.		Free	>	Cover crop			1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop	>	Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop		Free	1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop		Free	1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop		Free	1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
		Chem.		Cover crop		Free	1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			1000	*	Gley brownsoil	Perridge	England
Chem.		Free		Cover crop			700	*	Loamy clay	Radcoat	England
		Chem.		Cover crop		Free	700	*	Loamy clay	Radcoat	England
		Chem.		Cover crop		Free	700	*	Loamy clay	Radcoat	England
Chem.		Free		Cover crop			700	*	Loamy clay	Radcoat	England

Table 3. Summary of controlled trials across Europe examining the effect of cover crop on growth of woody plants compared with other weed management techniques. For each study, the effect of the different weed management techniques is ranked, beginning from the left, in order of the most positive impact followed by the second most positive and so forth: = indicates non-significant response between treatments; > indicates significant difference between treatments. Annual rainfall data were extracted from the papers and, if measured during the experiment, pooled to a mean. Where data were missing, national databases were used to extract data on mean annual precipitation for the region.

Reference	Woody species	Cover crop species
Albertsson et al., 2016	*Salix Tordis/Gudrun*	*Trifolium repens & Trifolium resupinatum*
Dupraz et al., 1998	*Juglans nigra*	*Onobrychis sativa*
Dupraz et al., 1999	*Juglans nigra x regia*	*Medicago sativa*
Hànninen, 1998	*Betula pubescens*	*Trifolium incarnatum*
Hànninen, 1998	*Betula pubescens*	*Trifolium resupinatum*
Hànninen, 1998	*Betula pubescens*	*Trifolium subterraneum*
Hànninen, 1998	*Betula pubescens*	*Trifolium pratense*
Hànninen, 1998	*Betula pubescens*	*Trifolium repens*
Hànninen, 1998	*Betula pubescens*	*Trifolium hybridum*
Hels et al., 2002	*Species rich mixture*	*Lolium perenne*
Hels et al., 2002	*Species rich mixture*	*Lolium perenne*
Hytönen & Jylhä, 2005	*Betula pendula*	*Trifolium repens*
Jylhä & Hytönen, 2006	*Picea abies*	*Trifolium repens*
Jylhä & Hytönen, 2006	*Pinus sylvestris*	*Trifolium repens*
Kjaerbolling,1995	*Fagus sylvatica*	*Medicago sativa & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Lotus corniculatus & Cichorium intybus*
Kjaerbolling,1995	*Fagus sylvatica*	*Aegopodium podagraria & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Fagus sylvatica*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Kjaerbolling,1995	*Quercus robur*	*Medicago sativa & Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Lotus corniculatus & Cichorium intybus*
Kjaerbolling,1995	*Quercus robur*	*Aegopodium podagraria & Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Quercus robur*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Kjaerbolling,1995	*Fagus sylvatica*	*Medicago sativa & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Lotus corniculatus & Cichorium intybus*
Kjaerbolling,1995	*Fagus sylvatica*	*Aegopodium podagraria & Phacelia tanacetifolia*
Kjaerbolling,1995	*Fagus sylvatica*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Fagus sylvatica*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Kjaerbolling,1995	*Quercus robur*	*Medicago sativa, Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Lotus corniculatus & Cichorium intybus*
Kjaerbolling,1995	*Quercus robur*	*Aegopodium podagraria, Phacelia tanacetifolia*
Kjaerbolling,1995	*Quercus robur*	*Linum usitatissum & Trifolium repens & Trifolium incarnatum*
Kjaerbolling,1995	*Quercus robur*	*Achillea millefolium & Papaver rhoeas & Centaurea cyanus*
Paris et al., 1995	*Juglans regia*	*Medicago sativa*
Paris et al., 2005	*Juglans regia*	*Trifolium subterraneum*
Sæbø et al., 2009	*Abies nordmanniana*	*Trifolium repens*
Willoughby & McDonald, 1999	*Pinus nigra*	*Brassica oleracea*
Willoughby & McDonald, 1999	*Pinus nigra*	*Meadow mixture*
Willoughby & McDonald, 1999	*Acer platanoides*	*Brassica oleracea*
Willoughby & McDonald, 1999	*Acer platanoides*	*Meadow mixture*
Willoughby, 1999	*Pseudotsuga menziesii*	*Trifolium repens*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hordeum spp.*
Willoughby, 1999	*Pseudotsuga menziesii*	*Brassica oleracea*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hypericum androsaemum*
Willoughby, 1999	*Pseudotsuga menziesii*	*Lupinus arboreus & Lathyrus sylvestris*
Willoughby, 1999	*Pseudotsuga menziesii*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Pseudotsuga menziesii*	*Prunella vulgaris & Plantago lanceolata*
Willoughby, 1999	*Pseudotsuga menziesii*	*Galium saxatile & Prunella vulgaris*
Willoughby, 1999	*Pseudotsuga menziesii*	*Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Pseudotsuga menziesii*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata*
Willoughby, 1999	*Pseudotsuga menziesii*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata & Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Fraxinus excelsior*	*Trifolium repens*
Willoughby, 1999	*Fraxinus excelsior*	*Hordeum spp.*
Willoughby, 1999	*Fraxinus excelsior*	*Brassica oleracea*
Willoughby, 1999	*Fraxinus excelsior*	*Hypericum androsaemum*
Willoughby, 1999	*Fraxinus excelsior*	*Lupinus arboreus & Lathyrus sylvestris*
Willoughby, 1999	*Fraxinus excelsior*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Fraxinus excelsior*	*Prunella vulgaris & Plantago lanceolata*
Willoughby, 1999	*Fraxinus excelsior*	*Galium saxatile & Prunella vulgaris*
Willoughby, 1999	*Fraxinus excelsior*	*Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Fraxinus excelsior*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata*
Willoughby, 1999	*Fraxinus excelsior*	*Silene dioica & Stachys sylvatica & Geum urbanum & Alliaria petiolata & Hyacinthoides non-scripta & Primula veris & Allium ursinum*
Willoughby, 1999	*Fraxinus excelsior*	*Trifolium repens*
Willoughby, 1999	*Fraxinus excelsior*	*Brassica oleracea*
Willoughby, 1999	*Fraxinus excelsior*	*Festuca ovina & Festuca longifolia*
Willoughby, 1999	*Fraxinus excelsior*	*Prunella vulgaris & Plantago lanceolata*

							Rain mm	pH	Soil	City	Country
Mech. Chem.	>	Mech.	>	Cover crop			630	7.4	Clay-Silty	Alnarp	Sweden
				Cover crop		Free	1131	8.4	Silt sand soil	Montpellier	France
				Cover crop		Grass	860	8.4	Silt sand soil	Montpellier	France
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Mech.		Cover crop	>	Grass	510	6.3	Silty loam soil	Kempele	Finland
		Chem.	>	Cover crop		Free	730	n.a.	Sandy	Djursland	Denmark
		Chem.	>	Cover crop		Free	645	n.a.	Clay	Sjaelland	Denmark
		Chem.	>	Cover crop		Mulch Free	620	n.a.	Mineral soil	Vilppula	Finland
Chem.	>	Mulch		Cover crop		Free	620	n.a.	Mineral soil	Vilppula	Finland
Chem. > Mulch		Free		Cover crop			620	n.a.	Mineral soil	Vilppula	Finland
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free	>	Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free	>	Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free		Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free	>	Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
Chem.	>	Free	>	Cover crop			726	n.a.	Heavy clay	Lisbjerg	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
		Chem.	>	Cover crop		Free	978	n.a.	Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978	n.a.	Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978	n.a.	Sandy	Lovbakke	Denmark
Chem.	>	Free		Cover crop			978	n.a.	Sandy	Lovbakke	Denmark
Plastic	>	Mech.	>	Cover crop			835	6.5	Sandy clay loam	Orvieto	Italy
Plastic	>	Mech.	>	Cover crop		Free	835	6.6	Loamy sand	Orvieto	Italy
Chem.		Mech.		Cover crop		Free	1365	n.a.	Mineral soil	Saerhim	Norway
		Chem.		Cover crop	>	Free	750	7	Silty	Winchster	England
		Chem.	>	Cover crop		Free	750	7	Silty	Winchster	England
		Chem.	>	Cover crop	>	Free	750	7	Silty	Winchster	England
		Chem.	>	Cover crop	>	Free	750	7	Silty	Winchster	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.		Free	>	Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free	>	Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	1000	n.a.	Gley brownsoil	Perridge	England
Chem.	>	Free		Cover crop			1000	n.a.	Gley brownsoil	Perridge	England
		Chem.	>	Cover crop		Free	700	n.a.	Loamy clay	Radcoat	England
		Chem.	>	Cover crop		Free	700	n.a.	Loamy clay	Radcoat	England
		Chem.	>	Cover crop		Free	700	n.a.	Loamy clay	Radcoat	England
Chem.	>	Free		Cover crop			700	n.a.	Loamy clay	Radcoat	England

Impact of cover crops on survival and growth of woody plants – overall patterns

The abiotic and biotic variations between the trials summarised above indicate a need for caution when comparing the findings. However, this variation adds reliability to findings that remain consistent across the trials. In the following, we summarise these general patterns.

The effect of cover crops on survival and growth of woody plants has mainly been compared with that of chemical weed control and free development of resident vegetation (control treatment). Comparisons of cover crops with mechanical weed control (e.g. Paris et al. 1995,2005; Hànninen 1998; Albertsson et al. 2016) and mulches (Hytönen and Jylhä 2005; Jylhä and Hytönen 2006; Paris et al. 1995, 2005) are surprisingly scarce. This may reflect the fact that most of the trials reviewed have been conducted in an afforestation context, rather than an urban green space management context.

When comparing the effect of different treatments, the most obvious and also quantitatively best supported pattern is for chemical weed control to result in (often significantly) higher survival and especially growth rate of young woody plants compared with all other treatments, cover crops included (Figs. 4 and 5).

A second pattern, although supported by a markedly lower number of comparisons, is for growth of woody plants to be significantly higher as a rule in the cover crop than in sown grasses (Fig. 5, Table 2). The only reported deviation from this pattern is in a study where the extremely competitive *Medicago sativa* is used as a monoculture cover crop (Dupraz et al. 1998) (Table 2).

A third pattern is for mechanical weed control to repeatedly result in higher survival and growth rates of woody species, compared with cover crops. However, the differences are rarely significant (Figs. 4 and 5). In fact, differences between cover crop and mechanical weed control are significant only when the soil is kept entirely clear by labour-intensive manual weeding (e.g. Paris et al. 2005) or in cases where the cover crop includes species known to be very strong competitors (e.g. *Trifolium repens* (Albertsson et al. 2016) or *Medicago sativa* (Paris et al. 1995)).

In comparison with the rather consistent patterns described above, the ranking of cover crops compared with free succession of resident weeds shows a split pattern. In approximately half of all published comparisons, woody plants have higher survival and growth in cover crop treatments compared with free succession controls, while in the other half the opposite is true (Fig. 5). Differences between the two treatments are seldom significant, however. In the few comparisons in which growth of woody plants differs significantly between the two treatments, these differences are explained as follows:

- In the five comparisons in which growth of woody plants is significantly higher in free succession plots, the cover crops include species known to be very strong (in retrospective too strong) competitors compared with woody plants. Such species include *Aegopodium podagraria*, *Trifolium repens* (Kjærbølling 1995) and *Festuca* spp. (Willoughby 1999).

- In the three comparisons in which growth of woody plants (*Acer platanoides* and *Pinus nigra*) is significantly higher in cover crops compared with free succession, the cover crop treatment is combined with a 1 m wide weed-free band around the woody plants, maintained through the use of herbicides (Willoughby and McDonald 1999).

Concerning the survival rate of woody plants, Willoughby (1999) report clear statistically significant differences between cover crops and free development of resident weeds, with survival rates of *Fraxinus excelsior* being significantly higher in 10 different cover crop mixtures (Table 2, Fig. 4). However, those authors report the opposite when the cover crop is winter barley (*Hordeum vulgare*) sown at half the normal agricultural seed rate in the year of planting and re-sown in May in the second growing season. Interestingly, in that trial the survival of *Pseudotsuga menziesii* did not differ significantly between any of the cover crop mixtures and free development of resident weeds, demonstrating that functional traits of the woody species themselves should not be neglected (Willoughby 1999).

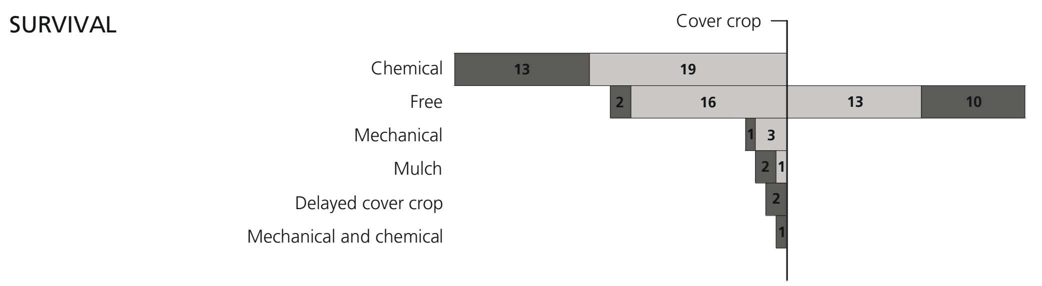

Fig. 4. Graphical overview of comparisons of survival rates of woody species in a cover crop and with other weed management techniques. The right and left side of the vertical black line show the number of comparisons where the woody plants show higher and lower survival rate, respectively, in the treatment compared with a cover crop. Light grey bars = survival rate not significantly different from survival in the cover crop treatment. Dark grey bars = survival rate significantly higher/lower than in the cover crop treatment.

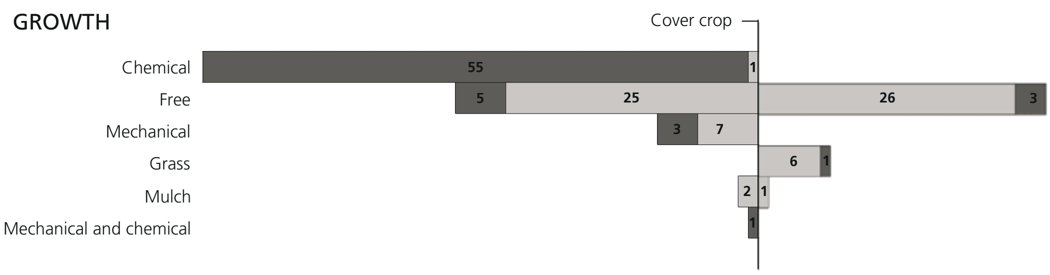

Fig. 5. Graphical overview of comparisons of growth rates of woody species in a cover crop and with other weed management techniques. The right and left side of the vertical black line show the number of comparisons where the woody plants show higher and lower growth rate, respectively, in the treatment compared with a cover crop. Light grey bars = growth rate not significantly different from survival in the cover crop treatment. Dark grey bars = growth rate significantly higher/lower than in the cover crop treatment.

A look at North American trials

In North America, Van Sambeek and Garrett (2004) have conducted a meta-review of findings from 110 reports on the effect of different weed management techniques on saplings and pole trees (i.e. > 3 cm diameter at breast (1.3 m) height) of black walnut (*Juglans nigra*) and other hardwoods. In their analysis, they assembled data from:

Trials testing cover crops as a weed control measure when establishing stands (i.e. afforestation). In this initial stage the root systems of young tree plants and cover crops both exploit the topsoil, causing competition for water and nutrients.
Trials introducing cover crops in established stands where the trees have had time to develop a deep root system (i.e. agroforestry), leading to some degree of root complementarity between the shallow root system of the cover crop and the deeper root system of the trees.

Due to merging of data from afforestation and agroforestry trials, caution is needed when comparing the results from North America against the patterns identified in European trials. Overall, however, the findings generally confirm the basic patterns observed in European trials. The average effect of different treatments on growth of North American hardwoods and other broadleaved trees is summarised in Table 4. According to these studies, sowing grasses markedly reduces tree growth compared with free development of resident weeds, with cereal grains being the exception (Van Sambeek 2010). Compared with free development of resident weeds and sown grasses, cover crops (legumes) increase tree growth, but not as much as 'classical' weed management techniques capable of keeping the soil free from resident vegetation. The North American findings also confirm European experiences on a more detailed level, showing e.g. that *Medicago sativa* is too competitive as a cover crop, reducing tree growth more than other cover crops tested and in fact also more than free development of resident weeds (Van Sambeek 2010).

Table 4. Mean growth of sapling and pole-size trees of North American hardwood and broadleaved species (Juglans nigra excluded) compared with free succession of resident vegetation, i.e. weeds. Data source: Van Sambeek and Garrett (2004)

Weed management technique	Mean growth
Mechanical	179%
Organic mulching	178%
Herbicides	172%
Cover crop	130%
Mowing	110%
Synthetic mulching	105%
Grasses	68%
Unmanaged, i.e. free development of resident weeds (baseline)	100%

Conclusions and perspectives

Jointly, the findings from controlled trials in Europe and North America provide strong empirical evidence that establishment of woody plants is favoured significantly by 'traditional' horticultural weed management techniques which keep the soil entirely free from competing weed, i.e. organic mulches, herbicides and intensive mechanical weeding. This comes as no surprise. However, one could argue that the development of practice in response to political and societal demands has actually 'overtaken' this empirically substantiated knowledge. Thus, when public organisations in Scandinavia and neighbouring countries are establishing woody plantings today, chemical weed control is seldom an option. Furthermore, budget restrictions often hinder prescription of intensive mechanical weed control. Similarly, application of mulches is costly and consequently only used on a small scale. Thus, in most cases, extensive mechanical weed management techniques or sowing of cover crops are the only alternatives to allowing the resident vegetation to develop freely. In this context, the results of the present review provide empirically substantiated information of relevance for contemporary weed management practice and professional perceptions.

A particularly relevant finding for contemporary professional practice is the weak empirical support for the prevailing view that mechanical weed control leads to significantly better survival and growth of woody plants compared with a cover crop treatment. Only in cases where the cover crop includes species known to be very strong competitors, or where the soil is kept entirely clear by labour-intensive manual weeding, can mechanical weed control give significantly higher survival and growth of woody plants compared with use of a cover crop. As argued by Kjærbølling (1995), this is most likely because mechanical weed control with tractor-mounted aggregates is of necessity are restricted to scalping/cutting weeds in the gaps between the plant rows, while leaving weeds in close proximity to the woody plants.

The low number of trials in which mechanical weed control has been studied poses a major constraint to generalisation on the validity of this finding. Thus future research should include intensive and extensive mechanical weed management techniques for comparison with cover crops and free development of resident weeds. Such studies should in particular cover sites with low and high populations of rodents, so that the effect of the cover crops on rodent damage to woody plants can be added as a variable.

However, the existing evidence base also shows that the choice between extensive mechanical weed control and cover crops is usually not a question about jeopardising the survival and growth of the woody plants, but rather about balancing cost and benefits and about the desired appearance of the planting, i.e. aesthetic considerations. Søren Holgersen, the editor of the professional Danish magazine *Grønt Miljø (Green Environment)*, addressed this in 1986:

> "As far as the aesthetic is concerned, the obstacle is the old cultivation tradition that has been uncritically passed on from arable fields and gardens to urban green spaces and nature areas. As a consequence, bare ground and pruning originally aimed at optimising crop production has become an aesthetic goal in itself. And it costs, because maintaining bare ground demands continuous cultivation/scalping. The alternative is to transform the aesthetic model from the neat cultivated garden at home to lush nature. A change of attitude is underway, but it is going slowly. Resistance to the use of chemicals and prospects for savings may speed it up?"
>
> (translated from Holgersen 1986)

Tests on wild flowers, woodland species and woodland edge species as cover crops (e.g. Willoughby 1999) may support Holgersen's prediction of a change of attitude. However, the large diversity of species and species mixtures that has been tested within individual trials and between trials also indicates that the fundamental basis of the technique is still not fully established (Willoughby et al. 2009).

From the above review of the literature, it is clear that cover crops which are capable of suppressing the resident vegetation (i.e. weeds) also exert competition on the woody plants. The literature shows that perennial grass and the most competitive legumes, like *Medicago sativa* and partly also *Trifolium repens*, are equal or even stronger competitors for woody plants than the resident weeds and thus should be avoided. The literature provides less clear guidance when selecting species with low competitiveness to trees, as clearly illustrated by the split pattern in ranking of cover crops versus free development of resident weeds. More empirical testing is needed concerning appropriate mixtures of species and their coexistence in a community that is well adapted for different site conditions and capable of suppressing resident weeds.

The clear majority of the cover crops tested in controlled trials have been composed of cultivars of native and non-native species used in conventional commercial agriculture/horticulture. However, wild flower mixtures are also frequently mentioned as an option and have also been tested. For example, Dassot and Collet (2015) successfully used 'a natural community' as a cover crop. Acknowledging that the empirically substantiated knowledge base is still very limited, the contemporary discourse on ecosystem services and the political and societal awareness about using local species to avoid biotic homogenisation are likely to encourage more tests on local wild flower mixtures as cover crops.

Fig. 6. A wide range of species and species mixtures have been tested as cover crops. Complex mixtures with native wild flower species increase the perceived naturalness, while simple mixtures with a uniform appearance increase the perceived stewardship. Photo: Nané Køllgaard Pedersen, DLF trial area 2016.

Fig. 7. A pocket wood at Klaksvigsgade, Copenhagen. November 2014, 300 woody plants were planted by landscape architecture students from Copenhagen University to replace a conventional street tree planting of six Fraxinus sp. that were diseased. Other students sowed an annual cover crop mixture, which was in full blossom in September 2015 (bottom images).

4: Considerations related to the use of cover crops in woody plantings

Balancing management objectives

When establishing plantings of woody species, the choice of weed management technique is inevitably an act of balancing many aspects, including site characteristics, costs, environmental impact and, not least, the management objectives in terms of desirable growth rate of the woody plants and their appearance during the establishment phase. No weed management technique is optimal with regard to all these aspects, as shown schematically in Figure 8.

As this review has demonstrated, use of a cover crop is neither the least nor the most supportive method for rapid establishment and growth of woody plants. Moreover, it is not the most or the least costly measure during the standard three-year establishment phase. In addition, cover crops do not support the highest or lowest degree of perceived stewardship or naturalness during the establishment phase. Rather, a cover crop balances different aspects and offers a possibility especially when environmental sensitivity and a lush, but stewarded, appearance are prioritised. However, even in cases where this is a priority, critical thinking and common sense are needed when adapting the following considerations to a given local social, environmental (e.g. the risk of rodent damage and late spring frost) and economic context.

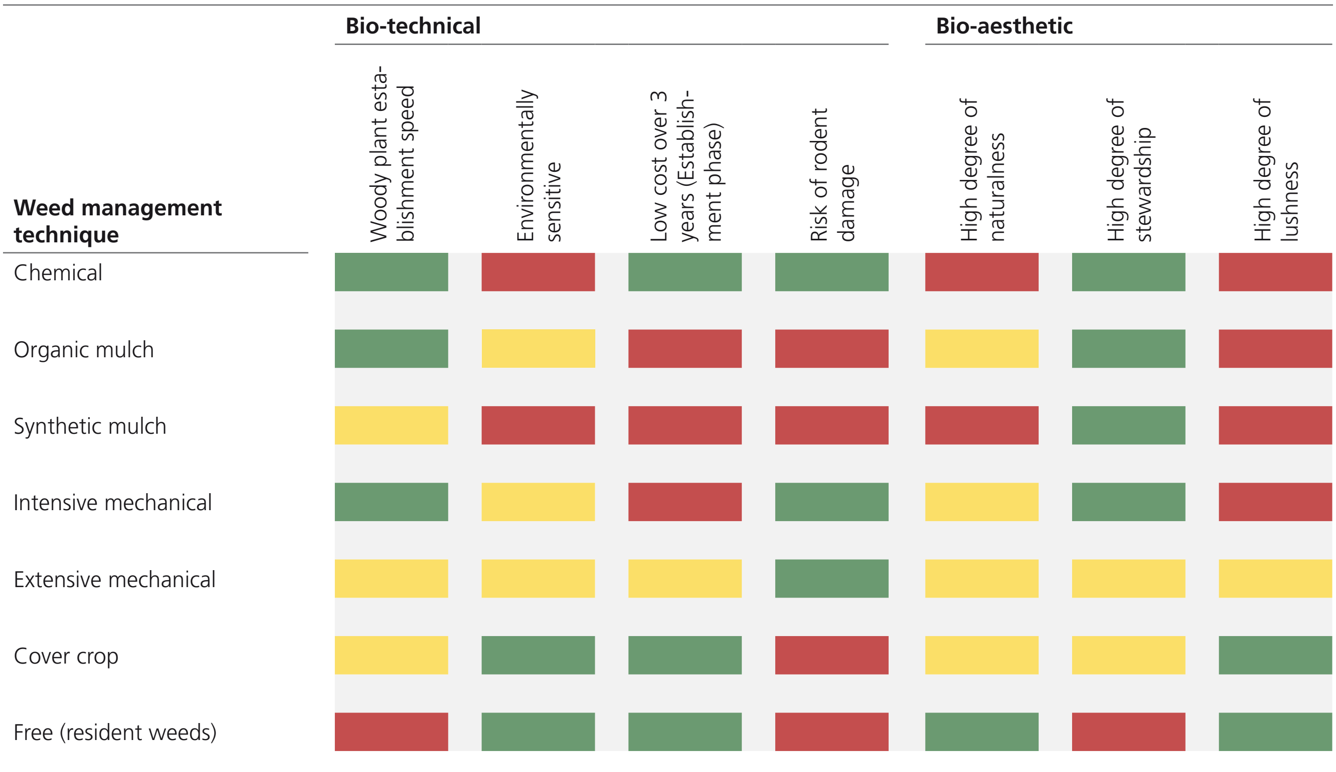

Fig. 8. Schematic summary of the merits of different weed management techniques in terms of different bio-technical and bio-aesthetic factors influencing decision making when prescribing management of woody plantings. A traffic light colour code is used to give a rough grading of 'Stop' (red), 'optional' (yellow) and 'go' (green).

Composing cover crops

Phenology and functional traits

For a cover crop to be successful as a weed management technique in woody plantings, it should be capable of (Holmgaard 1987; Kroff et al. 1992; Bastians et al. 1997):

- Rapid leaf area development after germination
- Early height growth
- Continuous and dense coverage of the soil surface early and late in the growing season
- Weak competition with woody plants

Individual species possess different combinations of these phenologies and functional traits to various extents, but no single species possesses all of them (Sørensen

*Table 5: Characteristics of common cover crop species used successfully to control weeds when establishing woody plantings in Northern Europe. Life cycle: I = annual, II = biannual/winter annual, III = perennial. Height: h = low (< 40 cm), hh = medium (40-60 cm), hhh (< 60 cm). Germination speed: g = slow, gg = medium, ggg = rapid. Ground coverage: c = low, cc = medium, ccc = extensive. Nitrogen fixing: x = yes. Seed rate: for monoculture modified from Sørensen and Juul (1993). Seed weight: derived from Fitter and Peat (1994) and the Ecoflora and LEDA databases, shown to only one decimal place. Seeding density: g per m^2/(seed weight mg/1000). Origin: w = wildflower in Denmark and southern Sweden, c = cultivated plants that have naturalised in Denmark and southern Sweden and cultivars used in agriculture/horticulture. Pollinator value derived from Kirk and Howes (2012): HB = honeybees, ST = short-tongued bumblebees, LT = long-tongued bumblebees, SB = solitary bees: * = low value; ** medium value; *** high value. na = data not available.*

Species	Life cycle	Height	Germination speed	Coverage of soil surface	Nitrogen fixing	Seed rate (g/m²)	Seed weight (mg)	Seeding density (n/m2)	Origin	Colour of flowers	Pollinator value				Comment
											HB	ST	LT	SB	
Achillea millefolium	III	hh	g	g		na	0,2	na	w	white	**	**	*	***	Self-supporting stems
Anthemis tinctoria	II/III	hh	gg	c		0,5	0,4	1310	c	yellow					Only used in mixture
Brassica oleracea	II	hhh	gg	gg		na	5,3	na	c	yellow	***	**	**	*	Deep rooting system
Cichorium intybus	III	hhh	gg	c		1	1,8	560	c	blue	**	**	**	*	Sheltered microclimate, tall
Fagopyrum esculentum	I	hh	ggg	cc		10	18,5	540	c	white	***	*	*	*	Preferred by browsers
Linum usitatissimum	I	hhh	gg	c		2	5,1	395	c	blue	**	*	*	*	Open structure
Lotus corniculatus	III	h	g	cc	x	1	1,4	700	w	yellow	**	***	***	***	Large soil amplitude
Ornithopus sativus	I	h	g	ccc	x	2	3,6	550	c	pink	**	**	**	*	For poor soils
Phacelia tanacetifolia	I	hhh	ggg	cc		1	1,2	835	c	blue	***	**	*	*	Intensive flowering
Prunella vulgaris	III	hh	g	cc		na	0,6	na	w	purple				*	For rich soils
Sanguisorba minor	III	hh	gg	ccc		1,5	4,2	350	w	brown					High durability
Secale cereale	I/II	hhh	gg	c		10	na	na	c						Sheltered microclimate, tall
Trifolium incarnatum	II	hh	gg	ccc	x	2	2,8	700	c	red	***	***	***	*	Avoid cultivars
T. pratense	III	h		c	x	na	1,4	na	w	red	**	**	***	*	Avoid cultivars
T. subterraneum	I	h	gg	ccc	x	2	5,5	365	c	white					Low and dense

and Juul 1993). Findings from controlled trials across Europe confirm this. Thus, monoculture cover crops are often reported as a failure, either because the plant did not establish well, or because conversely it developed too much and competed strongly with the young trees (e.g Willoughby 1999; Balandier et al. 2009). Indeed, practical experience in Denmark, Germany and France (Sørensen and Juul 1993; Reinecke 2000; Balandier and Prévosto 2015) has shown that mixed cover crops are more beneficial than single-species cover crops as a weed management technique when establishing plantations of woody species. However, this is only true if the mixture is well composed.

Table 5 provides an overview of phenological and functional traits of the most common cover crop species that have been used with success in controlled trials in Northern Europe, and species where we have local, but more qualitative, experiences in Denmark and southern Sweden. These species are also described in detail in Chapter 5.

Fig. 9. Monocultural cover crop of Phacelia tanacetifolia in which resident weeds of perennial grasses have established profusely. Toekomstbeeld Scheldevelde, Ghent, Belgium. Photo: Anders Busse Nielsen, June 2015.

Species mixture

The positive effect of species mixtures arises due to the combination of species with different phenology, functional traits and life cycles. The species mixture should consist of herbaceous species with rapid leaf area development from seed, species with dense foliage and preferably also annual, winter annual (biennial) and perennial species to provide cover from early stages until the canopy of the woody plants closes up and shades the ground.

The number of species varies greatly between cover crops tested in European trials (see Tables 2 and 3). Balandier et al. (2009, referring to Reinecke 2000) use a mixture of 11 species, whereas Danish experiences support the use of more simple mixtures of two to five species, where each species is selected to fulfil a specific role, e.g. rapid leaf area development (Sørensen and Juul 1993).

Uniform sowing of the species in a mixture is important for the cover crop to succeed. The risk of de-mixing, i.e. uneven distribution, of the species during sowing increases when the seed size and weight differ markedly between the species (Sørensen and Juul 1993; Hitchmough 2017). Seed size also influences the depth of sowing for optimal germination, where small seeds should generally be sown at more shallow depth than larger seeds. Therefore, seed size and weight are important considerations, with a mixture with seeds of comparable size and sowing depth being desirable.

The 'optimal' time of sowing also varies greatly between individual cover crop species. Many species need a warmer period for rapid germination and, for these, sowing in spring, from late April to early June, can be suitable. Other species, like many wild flowers, need stratification (i.e. a period of frost) in order to germinate, which suggests sowing in autumn. Therefore, the intended timing of sowing is an important consideration when composing mixed cover crops.

Cautious use of non-native species

When cover crops are introduced to urban and rural landscapes, there is a continuing risk of dispersal to surrounding habitats and ecosystems. Thus, while cover crops are generally selected as a weed management technique with potential for supporting biodiversity, inclusion of very aggressive species (native and non-native) could also pose a threat to local biodiversity, including habitats and plant species. *Lupinus polyphyllus* is an example of an introduced species that has become invasive. It was introduced as a cover crop species for improving and/or stabilising soil and as an ornamental species for gardens. Today, this species is listed as an invasive species throughout Scandinavia and parts of Europe (www.nobanis.org), as it has spread wildly and is held to have a negative impact on the local flora.

The European Network on Invasive Alien Species (NOBANIS), initiated by the Nordic Council of Ministers, provides a platform for consultation when implementing a cautionary approach to prevent unintentional dispersal of species (www.nobanis.org). Non-native species such as *Trifolium incarnatum, Fagopyrum esculentum* and *Phacelia tanacetifolia* are commonly found in cover crop mixtures, in which they are used to benefit the soil and the fauna or for aesthetic reasons, e.g. colourfulness. At present, these species are not classified as harmful or potentially invasive in Denmark and southern Sweden (www.nobanis.org).

Ellenberg indicator values as reference for cover crops with wild flowers

The contemporary discourse on ecosystem services and the political focus on hindering biotic homogenisation are encouraging the use of local wild flower mixtures as cover crops, despite the empirically substantiated knowledge base still being very limited.

Site-adapted local cover crops could be composed using the *Ellenberg indicator values* (EIV). Based on abiotic factors such as continentality, temperature, sunlight, soil moisture, soil reaction (pH), soil fertility (N) and salinity, more than 1500 plants have been described in their realized niche in Central Europe and the British Isles (Ellenberg et al. 1991; Hill et al. 1999).

Composing wild flower cover crop mixtures using EIV can be done either by: 1) site vegetation analysis and flora lists or 2) matching abiotic site conditions directly with the EIV scale. Benefits of *site vegetation analysis and flora lists* are the direct association with the specific site, as the EIV for the existing vegetation is used to provide ecological site information. This analysis acts as a guide in selection of robust and persistent species sharing EIV values with the existing species. Where natural soils have been destroyed and replaced with artificial soil substrates, it may be possible to use the EIV scale for matching soil (texture and physical) composition. Soil reaction (pH), soil fertility (N) and salinity are the most obvious and directly applicable EIV values for this purpose. Since new woody plantings are highly exposed to direct sunlight, this EIV should also be taken into consideration.

Inclusion of nitrogen-fixing species

Nitrogen tends to be the nutrient most often limiting tree growth (Van Sambeek and Garrett 2004), and cover crops generally include legumes (Fabaceae) with the ability to fix atmospheric nitrogen. Unless heavily fertilised, most forage legumes on average obtain about 75% of their nitrogen through the fixation process, and some of this nitrogen becomes available to the trees when plant residues decompose and organic nitrogen is converted to ammonia or nitrate nitrogen (Van Sambeek and Garrett 2004). However, in European trials cover crops including legumes do not show a general pattern of being more supportive for the growth of woody plants than cover crops where legumes are not included. In their meta-review of North American studies, Van Sambeek and Garrett (2004) found substantial variations in the effect of different legume species on young woody plants, with e.g. *Medicago sativa* being too competitive. Those authors also, in coherence with Hànninen (1998) found that annual and biannual legumes tend to reduce tree growth less than perennial legumes, suggesting that subterranean clover (*Trifolium subterraneum* L.) and crimson clover (*Trifolium incarnatum* L.) may be excellent choices. However, both species need to be mixed with perennial species in order for the cover crop to sustain soil coverage over the typical 3- to 5-year establishment period of woody plants.

Height of cover crops

In mixed agricultural cropping systems, the maximum height of the cover crop and the related shading effect have been found to have a negative impact on biomass production in the main crop (Hollander et al. 2007b). Generally, woody species are more shade-tolerant than agricultural crops (Grime 2001; Van Sambeek et al. 2007) and in both Denmark and Germany there are positive experiences of using cereals such as rye (*Secale* sp.) to shelter woody plantings from wind and sunburn at exposed sites (Cotta 1822 cit. Balandier et al. 2009) (Fig. 11). Studies of land reclamation following mining in North America also report positive results of using rye (Franklin and Buckley 2006). Nielsen (1997) proposes including a high cover crop species that provides wind shelter and related microclimate benefits for woody plants, in addition to the lower-growing species in the cover crop mixture.

However, preliminary results from ongoing trials show that cover crops containing species with dense foliage (e.g. cultivars of *Trifolium pratense* and *Trifolium incarna-*

Example – trial in Ringkøbing K

The Ellenberg indicator values (EIV) have been applied to develop a native cover crop seed mixture that is now being tested as part of a controlled trial in an afforestation located in Ringkøbing K, Denmark. This is a nature city district (naturbydelen) where green infrastructure consisting of forests, orchards and meadows is being established on former agricultural land prior to housing development. The site is located on the coast of the Ringkøbing fjord (56°04’25.1”N 8°16’52.8”E) and has a sandy soil. The spontaneous flora contains many plants normally associated with disturbed arable soils and indicator species of the coastal location, e.g. *Armeria maritima* and *Plantawgo maritima*.

In developing the species mixture, the local flora was analysed and their EIVs were used as a guide and reference for selecting species to be included in the cover crop (Table 6). The mixture comprises annual, biennial, short- and long-lived perennial hemi-chryptophytes and has been composed to flower from May through to October (Fig. 10), with species selected to have high value for pollinating insects. The mixture also includes control plants expected to have low emergence rates. The control plants *Anthyllis vulneraria* and *Trifolium arvense* are normally associated with very dry and acid soils. The experimental site was established in 2016. Apart from *Echium vulgare* and *Trifolium arvense*, all the experimental species in the cover crop have established well. However, the *Trifolium pratense* provided was unfortunately the highly productive (aboveground biomass) and dominant *Trifolium pratense* var. *sativum cultivar* rather than the smaller native wild-growing species. Data collection will continue until 2018.

Fig. 10. Cover crop of wild flowers composed based on Ellenberg indicator values for sandy soil. The cover crop is a mixture of Achillea millefolium, Anthyllis vulneraria, Barbarea vulgaris, Echium vulgare, Knautia arvensis, Leucanthemum vulgare, Lotus corniculatus, Papaver rhoeas, Trifolium arvense and Trifolium pratense. It is being used in a controlled trial running from 2016 to 2018 in Ringkøbing K, Denmark. Image from summer 2017 when Anthyllis vulneraria, Leucanthemum vulgare, Lotus corniculatus and Papaver rhoeas were flowering. Photo: Mona Chor Bjørn.

*Table 6. Characteristics of a cover crop composed of a site-adapted local wild flower mixture developed for the Ringkøbing K afforestation. Life cycle: I = annual, II = biannual/winter annual, III = perennial. General information on plant height, lifeform derived from Hansen et al. (1999); www.floraweb.dk; www2.ufz.de/biolflor/index.jsp): h = low (< 40 cm), hh = medium (40-60 cm), hhh (< 60 cm). Ground coverage: c = low, cc = medium, ccc = extensive. Nitrogen fixing: x = yes. Ellenberg indicator values derived from Ellenberg et al. (1991) and Hill et al. (1999). Pollinator value derived from Kirk and Howes (2012): HB = honeybees, ST = short-tongued bumblebees, LT = long-tongued bumblebees, SB = solitary bees: * = low value; ** medium value; *** high value.*

					Ellenberg indicator										
Species	**Life cycle**	**Height**	**Coverage of soil surface**	**Nitrogen fixing**	**Light**	**Moisture**	**Soil pH**	**Nitrogen**	**Salinity**	**Colour of flowers**	**Pollinator value**				**Comment**
											HB	ST	LT	SB	
Achillea millefolium	III	hhh	c		8	4	6	5	1	white	**	**	*	***	Self-supporting stems
Anthyllis vulneraria	II	H			8	3	7	2	0	yellow	*	**	*	*	Control species
Barbarea vulgaris	II	hh	c		8	6	7	6	0	yellow	**	**	*	*	Self-supporting stems
Echium vulgare	II	hhh	c		9	4	8	4	0	blue	***	***	***	***	Self-supporting stems
Knautia arvensis	III	hh	c		7	4	8	4	0	purple	**	***	***	***	Self-supporting stems
Leucanthemum v.	III	hh	cc		7	4	7	6	0	white	*	*	*	**	Self-supporting stems
Lotus corniculatus	III	h	cc	x	7	4	7	3	0	yellow	**	***	***	***	Large soil amplitude
Papaver rhoeas	I	hh	c		6	5	7	6	0	red	**	**	*	**	Self-supporting stems
Trifolium arvense	I	h	cc	x	8	3	2	1	0	red	*	**	*	*	Control species
T. pratense	III	h	c	x	7	5	7	5	0	red	**	**	***	*	Avoid cultivars
Average EIV of cover crop mixture					**7,5**	**4,2**	**6,6**	**4,2**	**0,1**						
Average EIV of local flora					**7,3**	**5,4**	**6,2**	**5,3**	**1,7**						

tum) that become overgrown and cling on to the woody plants (so that no part of the woody plant biomass is above the cover crop) provide too much shade and also cause marked mechanical damage by direct leaf contact, particularly after heavy rain or strong wind when they collapse and drag down the woody plants.

Thus while Van Sambeek and Garrett (2004) argue that species which have decumbent stems, such as *Trifolium repens* and *T. subterraneum*, or species that have vines, such as *Vicia villosa*, are excellent choices for cover crops because they require less biomass to effectively cover the soil compared with species that have an upright growth habit, such species should not grow to more than two-thirds of the height of the woody plants.

Cover crops with dense foliage that unintentionally cling on or grow to more than two-thirds of the height of the woody plants could be manually removed in the immediate vicinity of the woody plants. However, while this is manageable in smaller

Fig. 11. Cover crops replaced mechanical weeding when new woodland plantations (30 ha) in the Sletten city district and landscape laboratory, Holstebro, Denmark, were established. One of the cover crops included rye (Secale cereale) in order to create a sheltered microclimate for the woody plants, while Trifolium incarnatum (among others) provides a lower dense ground cover. Top left photo: interface between cover crops with (at the back) and without Secale cereale (in the foreground). Bottom left photo: the open shelter of Secale cerale over the Trifolium incarnatum. Right: the foliage of the woody plants is above the Trifolium incarnatum, but sheltered by the open Secale cereale matrix. Photos: Carl Aage Sørensen, 2005.

plantings, such post-sowing adjustments are labour-intensive in larger afforested areas. This encourages use of low cover crop mixtures, e.g. combined with planting of larger seedlings and/or implementing mechanical weeding in the first growing season to allow the woody plants to increase in height before the cover crop replaces mechanical weeding.

Perceived stewardship and naturalness

Well-established cover crops can increase perceived stewardship compared with free weed development, but not necessarily perceived naturalness. The latter depends largely on the cover crop species and their number and diversity in appearance. If a high degree of stewardship is desired, simple mixtures with a uniform character that links to agriculture and horticulture can be suitable, e.g. *Trifolium* species, cereals etc. In contrast, more complex mixtures with native wild flower species can increase the perceived naturalness of a woody planting during its establishment.

The height of the cover crop also affects the perceived visual and physical accessibility. In relation to this, Roovers et al. (2006) found that Belgian forest visitors perceived field layer vegetation taller than approximately 50 cm to be a significant obstruction to free movement. While people generally appreciate the perceived accessibility provided by low ground cover, low cover crops can also increase unintended wear and tear to the vegetation caused by human trampling, especially in densely populated areas (Kristensson 1991). This might have negative impacts on the long-term establishment of the vegetation (Gunnarsson and Gustavsson 1989; Kristensson 1991; Jansson et al. 2014).

The woody species and combinations of these are, of course, also important for the appearance and perceived character. A monoculture of trees will most likely contribute to a cultivated character and species-rich mixtures of trees and shrubs to a more natural character. Thus the choice of using a cover crop and how it is composed is not only a management consideration, but is in fact an important design parameter during the establishment phase of woody plantings, with a substantial influence on perceived sensory dimensions.

Seeding density

The capacity of a cover crop to suppress resident weeds is strongly related to seeding density. A higher seed rate and associated higher emergence and ground cover are directly related to the ability of a cover crop to reduce weeds (Uchino et al. 2011). However, the density of the cover crop also affects the competitiveness towards the woody plants. In their review of studies in the Eastern US on land reclamation following surface mining, Franklin et al. (2012) found that planted trees displayed a bell-shaped relationship to the relative ground cover of cover crops, with both low and very dense ground cover being disadvantageous for the woody species.

Experiences in Denmark show that woody plants develop most favorably if the seed rate of the cover crop is reduced to approximately one-third of the recommended rate for agriculture. (Sørensen and Juul 1993; Carl Aage Sørensen personal communication 2016). However, as the germination rate (field emergence) varies widely between species and is also affected by the actual sowing and seedbed conditions, this recommendation should be interpreted with caution. In general, commercial culti-

Table 7. Calculation of seed rate (g/m²) and seeding density (no. per m²) in mixed cover crops. For the individual species the seed amount when sown as a monoculture is used as reference, and divided by the percentage share of the species in the mixture. The species mixture used in the example is currently sold in Denmark as an 'afforestation mixture' (skovrejsningsblanding) by Nykilde and Prodana, and is being tested in a controlled trial 2016-2018 in the new city district Ringkøbing K.

Species	Rate (g/m²) in monoculture	% of mixture	Rate (g/m²) in mixture	Seed density per m²	Role in the mixture
Linum usitatissimum	2	25	0,5	99	Annual, rapid and intensive flowering. Strong straw supporting other species
Lotus corniculatus	1	10	0,1	70	Perennial, intensive flowering in second year, soil coverage late in season, nitrogen fixing
Ornithopus sativus	2	25	0,5	138	Annual, rapid germination, effective ground cover in first season
Sanguisorba minor	1,5	25	0,38	125	Perennial, dense ground cover, nitrogen fixating, durable
Trifolium incarnatum	2	15	0,3	105	Biannual, intensive flowering in late summer or early, when sown in spring and autumn, respectively. Dense ground cover, nitrogen fixing
Sum		**100**	**1,78**	**537**	

vars (e.g. of *Phacelia tanacetifolia* or *Trifolium pratense*) have higher emergence rates (e.g. Hànninen 1998; Uchino et al. 2011) than wild flower and ornamental perennial species described by Hitchmough (2017).

The recommendations made by Sørensen and Juul (1993) as regards seed rates (g/m²) for monocultures of different species (see Table 5) build on the above considerations. When composing mixed cover crops, the rule of thumb is to divide the seed rate (g/m²) by the percentage share of the species in question in the mixture. Table 7 provides an example of these calculations. The species mixture used in the example is currently sold in Denmark as an 'afforestation mixture' (*skovrejsnings-blanding*) by Nykilde and Prodana, and is being tested in a controlled trial 2016-2018 in the woodland planting in new city district Ringkøbing K.

Site preparation

The site preparation and sowing recommendations given below are modified for a Danish and southern Swedish context and draw on experiences reported by Kristensson (1991), Sørensen and Juul (1993) and Hitchmough (2017).

As this review shows, a well-composed and well-established cover crop can effectively suppress resident weeds from germinating and becoming dominant. Conversely, cover crops cannot reduce the abundance of resident weed propagules, and even the best cover crop cannot catch up with and suppress perennial weeds when the latter have a head start (Fig. 12). Therefore, thorough soil preparation ensuring soil free from weeds, especially perennial weeds, is just as important for the cover crop as it is for the woody plants to achieve good establishment.

The best time to reduce abundance of weed propagules is during site preparation, i.e. before the trees are planted. Only during site preparation can the soil be deeply cultivated and inverted (e.g. by ploughing) to 'bury' propagules of resident weeds (see also Chapter 2 of this report). In the optimal case, deep cultivation should be carried out a least one month prior to establishing the woody plants and/or sowing the cover crops (modified from Sørensen and Juul 1993). This allows the soil to 'settle' and enables two or three shallow cultivations of the surface soil (just the top 5 cm) to subdue eventual germinated weeds located in the surface soil (from seeds, rhizomes, taproots and root buds). These cultivations should be carried out when the soil surface is dry and when dry (and preferably windy) weather is forecast for the following days.

Sowing techniques

The sowing recommendations given below target the Danish and southern Swedish context and draw on experiences reported by Kristensson (1991), Sørensen and Juul (1993) and Hitchmough (2017).

Sowing should be carried out when the soil surface is 'workable', but still moist, and rain is forecast for the following week(s). After the cover crop has been sown, a shallow spring tine harrowing/racking or, at a minimum, a roller or cultipacker should go over the soil to ensure that there is good contact between seed and soil. If rain is not forecast for the following week, irrigation can support rapid germination of the seeds.

Smaller areas can easily be hand-sown. In fact, many wild flower species adapted to wind dispersal are best sown by hand or by a machine-mounted centrifugal disperser, mixed with sand, sawdust or granules. If the seed size varies substantially between the species, sowing in stages could be an option; beginning with sowing and cultivating in the largest seeds (e.g. *Secale cereale*) to desirable depth before sowing species with smaller seeds (e.g. *Lotus corniculatus*). However, this is often only practically feasible in cases where the cover crop is to be sown prior to planting of the woody species. Here an agricultural seed drill can be used, with a pneumatic seed ejection system to ensure that seeds of different sizes and weights are not separated during sowing.

Post-sowing management considerations

Mowing

Mowing shifts the competitive advantage in favour of grasses compared with forbs (Van Sambeek and Garrett 2004), which can have a negative effect on the growth of many trees, and the evidence for positive effects of mowing or trimming of cover crops seems weak (Van Sambeek and Garrett 2004; Van Sambeek 2010). Considering the additional cost and high risk of tree damage, as reported by e.g. Kristensson (1991), regular mowing or trimming of cover crops cannot be recommended. An exception is in edge zones facing e.g. paths, where trimming can induce cues to care (i.e. perceived stewardship) and even stimulate re-flowering of some species like *Lotus corniculatus*, producing a prolonged flowering display (Sørensen and Juul

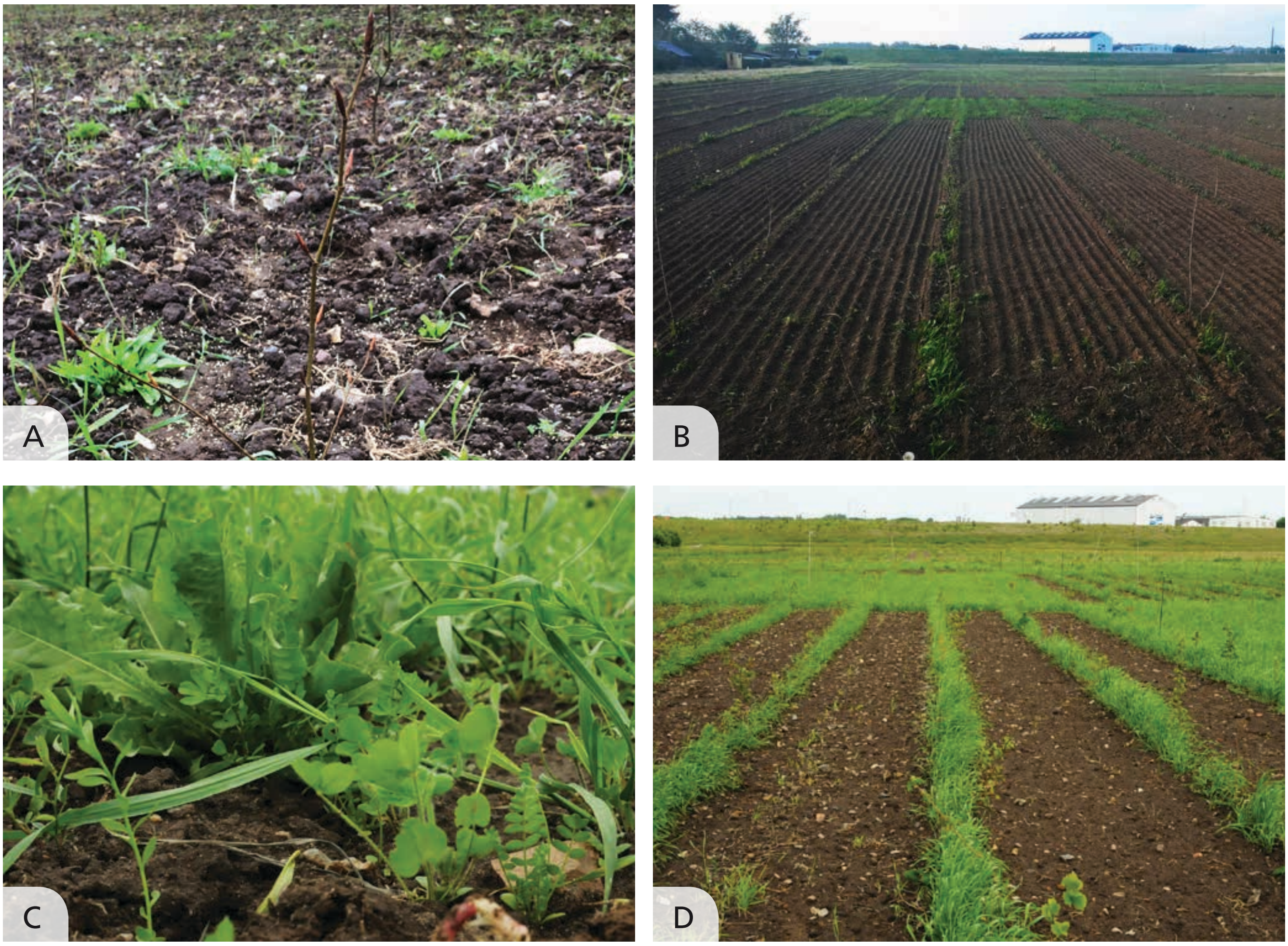

Fig. 12. Trial with cover crops established on a site where soil preparation had failed to suppress rhizomes of Elytrigia repens. A) 11 May, 2017. The seeds of the cover crop mixture and granules are visible on the soil surface, while Elytrigia repens has already germinated. B) 19 May, 2017. Just one week later, abundant Elytrigia repens clearly mark the location and square shape of unweeded plots, i.e. plots sown with cover crops. C) 8 June, 2017. Small seedlings of the cover crop species mixture (Linum usitatissimum, Lotus corniculatus, Ornithopus sativus, Sanguisorba minor, Trifolium incarnatum) surrounded and suppressed by Elytrigia repens, partly due to the weed having a head start. D) June, 2017: Full coverage of Elytrigia repens in the unweeded plots and within planted rows in plots of weeded with a tractor-mounted cultivator. In September 2017, the trial was cancelled and mechanical weeding was resumed in the entire area.

1993). A cut path through woody plantings with a lush cover crop can also induce 'cues to care' and enable people to experience the flowering close up (Fig. 13).

Selective weeding

Seeds of annual weeds like *Chenopodium album* or perennial weeds like *Artemisia vulgaris* and *Cirsium arvense* often germinate alongside the cover crop. Such widespread and fast-growing perennial species with massive seed production should be removed manually during the first season, in the same way as farmers walk their fields to pick wild oats (*Avena fatua*) before they disperse their seeds.

Fig. 13. Path cut into a lush cover crop of annuals sown in 2017 as interim ground cover prior to establishment of a new urban forest in Copenhagen. The path induces a 'cue to care' and enables people to experience the intensive flowering close up. Photo: Anders Busse Nielsen.

Fig. 14. The most common cover crop species used successfully to control weeds when establishing woody plantings in Northern Europe. Photos: Niels Jacobsen and Nané Køllgaard Pedersen

5: Phenology and functional traits of commonly used cover crop species

In this chapter, some of the most common cover crops suitable for Denmark and most of southern Sweden are described. The information is based on Sørensen and Juul (1993), Hansen et al. (1999), Mossberg and Stenberg (2003), Naturhistoriska riksmuseet (2016) and FAO (2017). An overview of the species, together with seed weight from the LEDA trait database (Kleyer et al. 2008) and recommended seed rates (kg/ha) when using the species as monocultures, can be found in Table 5.

Achillea millefolium

Achillea millefolium (common yarrow) is a wintergreen forb with far-creeping rhizomes and large seed production. It is a short-lived polycarpic perennial that has a large distribution in the northern and southern hemisphere (Grime et al. 1988). It is normally associated with open exposed ground, on soils varying in pH from 4-8. *Achillea millefolium* flowers generously from June to October in Denmark and southern Sweden. It is absent from wetland, woodland and sand dunes.

Anthemis tinctoria

Anthemis tinctoria (golden marguerite) is a perennial plant with a large distribution over Europe and Asia, but is not native to Scandinavia. It is associated with grassland on open ground and is naturally often found on dry calcareous soils. *Anthemis tinctoria* flowers generously and for long periods, but is usually at its best from June to September.

Brassica oleracea

Brassica oleracea (wild cabbage) is native to coastal areas in southern and western Europe. However, it is a species that includes may common foods as cultivars, e.g. Brussels sprouts. It is a biennial plant that forms a large basal rosette in the first year. *Brassica oleracea* is not native to Scandinavia.

Cichorium intybus

During the first year, *Cichorium intybus* (common chicory) develops light-green basal foliage. In the second year, it produces self-supporting flowering stems (60-100 sometimes 200 cm) that flower from July to September. It is generally found on dry and nutrient-rich soils and develops well on high pH soils. *Cichorium intybus* is not native to Scandinavia, but is it often found on arable land, disturbed sites and roadside verges. The durability of the flowers is an important asset, and cutting of the flower stems in early summer can extend the flowering period in time and abundance.

Fagopyrum esculentum

Fagopyrum esculentum (common buckwheat) has been cultivated for centuries in Denmark and Sweden. It is native to southwestern China. *Fagopyrum esculentum* is an upright annual plant that flowers in June to July. It is commonly used as a cover crop in agriculture. *F. esculentum* is usable on light soils but the species is rather adaptable. It does not like cold soils so early seeding should be avoided as well as frost prone areas, which limits usability in some parts of Sweden. Can be sown during summer, where its rapid development from seed works well with more slowly growing cover crops. *F. esculentum* provides a moderate coverage of the soil surface.

Linum usitatissimum

Linum usitatissimum (common flax) is an upright annual plant that probably derives from wild species in the Mediterranean area and its surroundings. It flowers about two months after sowing, producing light-blue flowers. Due to its small foliage and delicate stems, it does not give a lot of shade to other species, making it very easy to intermix with other cover crops and with woody plants. *Linum usitatissimum* grows well on slightly acid to neutral soils, but can be more problematic on wet and heavy soils. In Scandinavia, it is generally found on arable land, roadside verges or brown fields.

Lotus corniculatus

Lotus corniculatus (birdsfoot trefoil) is a perennial legume from Western Europe (native in Denmark and Sweden) that develops slowly during the first growth season due to high root system investment, but grows rapidly from the second year. *Lotus corniculatus* flowers yellow in June-July (August), but re-flowers if it is exposed to grazing or cut-back. It is very robust to different soils and can tolerate both lighter and heavier soils, as well as dry and moist situations. However, due to its large plasticity and geographical range there seems to be great variation between different genotypes and seed sources.

Ornithopus sativus

Ornithopus sativus (common birdsfoot) is a common annual originating from Portugal and southern Spain that is widely grown in Denmark, but very rarely used in Sweden. It produces small white to slight pinkish flowers and reaches up to 30-40 cm in height. It develops well on acid and light soils but needs annual rainfall of 500 mm and above. It flowers rather early but takes more time to develop a good foliage cover. However, by the end of the season and during the winter it provides good soil cover. This development strategy is probably an adaptation to summer drought, since much energy is devoted to a deep root system in its earlier stages. As such, it can improve the soil structure on many sites.

Phacelia tanacetifolia

Phacelia tanacetifolia (blue tansy) is an annual plant (from California) with light-blue flowers that appear in June to August. It is usually erect (60 cm) in early growth stages, but has a tendency to lie down in heavy rain, which may suffocate some woody plants. The flowering period is long and usually starts about eight weeks from sowing and attracts many birds and bees. *Phacelia tanacetifolia* can adapt to a range of soils and is said to have low water consumption. It is robust to different sowing periods and taxonomically far away from many other cover crop species, which makes it easy to intermix without fear of allopathic reactions.

Prunella vulgaris

Prunella vulgaris (selfheal) is a native short-lived perennial plant that is associated with grassland vegetation on moist soils. *Prunella vulgaris* subsp. is found across the northern hemisphere, in Europe, Eastern Russia and North America. It flowers generously from July to August. It is a small wintergreen semi-rosette plant that spreads through runners. It is favoured by close grazing or cutting (Grime et al. 1988).

Sanguisorba minor

Sanguisorba minor (salad burnet) is a rosette-forming perennial plant with large geographical distribution and is found in parts of Europe, Asia and Africa. It develops dense foliage, especially after the first growth season that gives good ground cover, with flowering stems reaching a height of 40-60 holding up small brown-red flowers. The flowering period is long but generally peaks in June to early July. *Sanguisorba minor* can adapt to a wide range of soils, but is naturally found on open, dry and calcareous soils (Grime et al. 1988).

Secale cereale

Secale sp. (rye) belongs to the grass family, Poaceae. It is a highly cultivated genus and commonly used in agriculture in Europe. In Denmark and Sweden, the winter annual *Secale cereale* is common on arable land. This annual grass can reach 70-180 cm during the growing season. It is a wind-dispersed grass that flowers in June. In afforestation, it is used to provide a sheltered microclimate for the woody plants.

Trifolium incarnatum

Trifolium incarnatum (crimson clover) is an annual from southern Europe reaching up to 40-50 cm in height. It has been introduced to Scandinavia and is often found on arable land, brown fields and roadsides. It is a plant that thrives on most soils except compacted, cold and wet soils. If sown in spring, it develops flowers after about three months and creates a winter cover of its almost woody residues. If sown in the late summer/autumn, it survives the winter as dense leaf rosettes that then flower in early summer. *Trifolium incarnatum* develops deep roots that are beneficial for the soil structure.

Trifolium pratense

Trifolium pratense (red clover) is a wintergreen grassland legume that is commonly found on open ground. It prefers neutral to slighly acid soild pH (pH 5.0 to 6.0) and moist soils. *Trifolium pratense* flowers from May to September. It is an important agricultural fodder and cover crop and therefore it is found across both the northern and southern hemisphere. Like other legumes, it has nitrogen-fixing root nodules formed in conjunction with the soil bacteria *Rhizobium trifolii* (Grime et al. 1988). *Trifolium pratense* is a native long-lived perennial, but it is often the short-lived, highly productive agricultural cultivar *Trifolium pratense* var. *sativum* that is commercially available.

Trifolium subterraneum

Trifolium subterraneum (subterranean clover) is in widespread use as an agricultural cover and fodder crop. It is a low annual clover that develops many low shoots. It can tolerate most soil conditions, but optimal development seems to occur on light soils with slightly acid to neutral pH. It grows fast after sowing and provides a fast soil cover. *Trifolium subterraneum* dies during the winter, but the plant residues provide some soil cover. If sown in summer, it goes through the winter as green foliage and flowers in the next year.

Appendix 1

List of species, with Latin, English, Danish and Swedish names.

Scientific name	English name	Danish name	Swedish name
Acer platanoides L.	Norway maple	Spidsløn	Skogslönn
Achillea millefolium L.	Yarrow	Alm. røllike	Röllika
Aegopodium podagraria L.	Ground-elder	Skvalderkål	Kirskål
Anthemis tinctoria L.	Yellow chamomile	Farvegåseurt	Färgkulla
Anthyllis vulneraria L.	Kidney vetch	Rundbælg	Getväppling
Armeria maritima Willd.	Thrift	Engelskgræs	Trift
Artemisia vulgaris L.	Mugwort	Gråbynke	Gråbo
Avena fatua L.	Wild-oat	Flyve-havre	Flyghavre
Barbarea vulgaris R.Br.	Winter-cress	Alm. vinterkarse	Sommergyllen
Brassica oleracea L.	Cabbage	Havekål	Kål
Chenopodium album L.	Fat-hen	Hvidmelet gåsefod	Svinmålla
Cichorium intybus L.	Chickory	Cikorie	Cikoria
Cirsium arvense (L.) Scop.	Creeping thistle	Agertidsel	Åkertistel
Echium vulgare L.	Viper's bugloss	Slangehoved	Blåeld
Elytrigia repens Desv.	Common couch	Alm. kvik	Kvickrot
Fagopyrum esculentum Moench	Buckwheat	Alm. boghvede	Bovete
Festuca longifolia Thuill.	Blue fescue	n.a.	n.a.
Festuca ovina L.	Sheep's-fescue	Fåresvingel	Fårsvingel
Fraxinus excelsior L.	Ash	Ask	Ask
Hordeum vulgare L.	Six-row barley	Alm. byg	Korn
Juglans nigra L.	Black walnut	Sort valnød	Svart valnöt
Knautia arvensis L.	Field scabious	Blåhat	Åkervädd
Leucanthemum vulgare (Vaill.) Lam.	Oxeye daisy	Hvid okseøje	Prästkrage
Linum usitatissimum L.	Flax	Alm. hør	Lin
Lolium perenne L.	Perennial ryegrass	Alm. rajgræs	Engelskt rajgräs
Lotus corniculatus L.	Birdsfoot trefoil	Alm. kællingetand	Käringtand
Lupinus polyphyllus Lindl.	Garden lupin	Mangebladet lupin	Blomsterlupin
Medicago sativa L.	Lucerne	Lucerne	Blålusern
Ornithopus sativus Brot.	Common birdsfoot	Serradel	Serradella
Papaver rhoeas L.	Common poppy	Kornvalmue	Kornvallmo
Phacelia tanacetifolia Benth.	Blue tansy	Honningurt	Honungsfacelia
Pinus nigra J.F.Arnold	Austrian pine	Østrigsk fyr	Svarttall
Plantago maritima L.	Sea plantain	Strandvejbred	Gulkämpar
Prunella vulgaris L.	Selfheal	Alm. brunelle	Brunört
Pseudotsuga menziesii (Mirb.) Franco	Douglas fir	Douglasgran	Douglasgran
Rumex spp.	Dock	Skræppe	Skräppa
Sanguisorba minor Scop.	Salad burnet	Bibernelle	Pimpinell
Secale cereale L.	Rye	Rug	Råg
Taraxacum spp.	Dandelion	Mælkebøtte	Maskrosor
Trifolium arvense L.	Hare's-foot clover	Harekløver	Harklöver
Trifolium incarnatum L.	Crimson clover	Blodkløver	Blodklöver
Trifolium pratense L.	Red clover	Rødkløver	Rödklöver
Trifolium repens L.	White clover	Hvidkløver	Vitklöver
Trifolium subterraneum L.	Subterranean clover	Jordkløver	Grävklöver

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