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Possibilities of Oil Radish Cultivation

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Thesis abstract

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In modern agriculture, the quest for sustainable and ecological practices has become paramount. This thesis explores the cultivation of oil radish that traces its origins back 5,000 years to China and examines its potential benefits and impact on soil health. While oil radish is widely recognized globally, its cultivation is relatively new in Finland, spanning approximately 30 years. Oil radish is known for its taproot and rapid growth. Its height can reach two meters in a very short time, and it can produce a significant amount of biomass per hectare.

The thesis primarily focuses on the soil-improving properties of oil radish, including soil structure enhancement, nutrient retention, weed suppression, and natural soil disinfection against pathogens such as nematodes. Furthermore, the thesis discusses alternative uses of oil radish for example in animal feed and oil production.

A field experiment conducted in the summer of 2023 at Seinäjoki University of Applied Sciences evaluated the impact of mulching on the recovery and root development of oilseed radish. The results showed that mulching had a major impact on the root growth, leading to significant differences in the biomass yield.

The thesis concludes with insights into the effects of the experiment on the soil structure and proposes directions for future research.

[1] Keywords: oil radish, renovation plant, soil improvement, biofumigation, sustainable agriculture

SEINÄJOEN AMMATTIKORKEAKOULU

Opinnäytetyön tiivistelmä

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Nykyajan maataloudessa pyritään löytämään uusia kestäviä ja ekologisesti ystävällisiä toimintatapoja. Tässä opinnäytetyössä tutustutaan öljyretikan käyttöön, jonka juuret ulottuvat aina 5000 vuoden taakse Kiinaan asti, ja sen potentiaalisista hyödyistä ja vaikutuksesta maaperän kuntoon. Vaikka öljyretikka on maailmalla varsin tunnettu kasvi, sen käyttö Suomessa on melko uutta, sitä on käytetty vain noin 30 vuoden ajan. Öljyretikka on tunnettu juurestaan ja sen nopeasta kasvuvauhdista, ja se voi saavuttaa jopa kahden metrin korkeuden todella lyhyessä ajassa ja merkittävän biomassamäärän hehtaaria kohden.

Opinnäytetyö keskittyy öljyretikan maanparannuskykyyn, kuten maanrakenteen parantamiseen, ravintoaineiden pidätyskykyyn, rikkakasvien torjuntaan ja luonnolliseen maan desinfiointiin taudinaiheuttajia, kuten ankeroisia, vastaan. Lisäksi työssä käydään läpi öljyretikan vaihtoehtoisia käyttökohteita, kuten sen käyttöä eläinten rehuna ja öljyntuotantokasvina.

Kesällä 2023 Seinäjoen ammattikorkeakoululla suoritettiin kenttäkoe, jossa arvioitiin murskauksen vaikutusta öljyretikan palautumiseen ja juuren kehitykseen. Tulokset osoittivat, että murskauksella oli suuri vaikutus juuren kasvuun, mikä johti merkittäviin eroihin kasvin biomassan tuotossa. Työn lopussa tutkitaan kokeen vaikutuksia maanrakenteeseen ja pohditaan mahdollisia lisätutkimuskohteita.

[1] Asiasanat: öljyretikka, saneerauskasvi, maanparannus, biofumigaatio, kestävä maatalous

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Terms and Abbreviations

Fresh Weight	The initial weight of the sample.
Biomass	The difference between the fresh weight and dry weight.
Dry Matter (%)	The percentage of dry matter in the sample.

1 INTRODUCTION

In modern agriculture, the search for sustainable and environmentally friendly methods has become one of the most important tasks. The global agricultural community is constantly seeking innovative solutions that not only increase natural soil productivity, but also minimize the environmental footprint left by traditional farming methods.

On 1 January 2023, the agreement on reform of the common agricultural policy (CAP) entered into force, where terms of commitment for environmental compensation 2023 (or Ympäristökorvauksen sitoumusehdot 2023) were also listed. The Finnish Food Authority explains that the environmental commitment is a five-year commitment that includes farm-specific and field-specific measures, where compensation is paid for the costs and loss of income caused by compliance with these measures (ruokavirasto.fi, 2023). One of the field-specific measures include oil radish as a soil improvement or renovation plant. A farmer can declare soil improvement plants or renovation plants for fields where annual production plants were cultivated in the previous year. Although a farmer cannot grow soil improvement plants as an underplant for a crop plant, and a maximum of 20 percent of the eligible area can be paid for the procedure.

This thesis is dedicated to oil radish (*Raphanus sativus*), a humble but versatile plant that trace back 5,000 years to China, believed to be the birthplace of the initial species of wild radishes. Historical records by the Greeks and 1st-century Roman agriculturalists first mentioned radishes as small, large, round, long, and sharp varieties of radishes (New Directions Aromatics, n.d.). Today, oil radish is gaining attention worldwide for its multi-faceted contributions to sustainable agriculture.

The purpose of this work is to explore the potential of the oil radish stems from recognition of the urgent need for agricultural practices that go beyond mere productivity metrics and actively contribute to the restoration and conservation of the environment. Oil radish provides unique characteristics that render it a compelling subject of study. It has demonstrated the potential to address critical challenges facing modern agriculture, from soil health improvement to pest management. The thesis will mainly examine the plant's impact on soil structure, nutrient cycling, and its ability to suppress weeds, but also will be mentioned its other potential agricultural uses.

2 OIL RADISH AS PLANT

Oil radish is an exceptionally vigorous plant, covering approximately 70% of the soil within a 60-day period, and it follows an annual planting cycle (Faria et al., 2018). Moreover, the green biomass production ranges from 20 t/ha to 35 t/ha, the dry mass production ranges from 4 t/ha to 8 t/ha, and the grains exhibit a yellowish-brown color with a diameter of 2 mm to 3 mm

2.1 Taxonomy

Oil radish is a coarse annual in the Brassicaceae (or Cruciferae) family. Its common alternate names are oilseed radish, forage radish or fodder radish (figure 1). Its scientific alternate names are *Raphanus sativus var. oleifera*, *Raphanus sativus L. ssp. oleiferus*, and *Raphanus sativus L. var. oleiformis*. The genus *Raphanus* includes several species of radishes, with *Raphanus sativus* being the cultivated radish commonly known tillage radish or daikon radish, Black Jack radish and Terranova radish (figure 2). The specific epithet *sativus* indicates that it is a cultivated or domesticated species. Oil radish was developed as a plowown and this is its primary purpose. It is also referred to as oil radish (McGill University, n.d.).

Figure 1. Oilseed radish in the summer 2023 (*Raphanus sativus var. Oleifera* variety *Valencia*) (Anna Vinogradova, 2023).

Figure 2. From left to right. Roots of Black Jack radish, Terranova radish and tillage radish or Daikon radish (Duff, 2020).

The taxonomic classification of oil radish can be perplexing. Certain literature distinguishes forage radish and oil radish as separate varieties, suggesting that oil radish possesses a stubbier, more branched root and a greater degree of winter hardiness than forage radish compared (Weil et al., 2006). Nonetheless, oil radish varieties can easily crossbreed, and clear distinctions remain poorly defined. Recommendations for their management and utilization generally apply uniformly across most varieties.

2.2 Roots

Oil radish is distinguished by its substantial, fleshy taproot (Figure 3), serving as the primary edible or usable component of the plant. The taproot, typically white, has the potential to attain significant sizes, influenced by the specific variety.

Figure 3. Oilseed radish root (Anna Vinogradova, 2022).

Various types of oil radish are available, displaying differences in root dimensions, form, and color. Daikon radish represents a distinct variety of oil radish, featuring an elongated and cylindrical taproot, commonly employed in diverse culinary uses.

Oil radish is well-regarded as a soil conditioner. Its central radish-shaped taproot, accompanied by an extensive system of hair roots, reaches deep into the subsoil, promoting loosening and aeration. The plant capacity to absorb soil nutrients, particularly nitrogen, and retain them throughout the winter, renders it an excellent choice as a cover crop (McGill University, n.d.).

Numerous farmers have noted that fields typically requiring fall plowing exhibit exceptional tilth in the spring when an oil radish stand is left undisturbed over the winter. Additionally, being a sulfurous crop, it contributes to warming the soil.

2.3 Plant body

Oil radish is characterized by rigid, straight hairs located near the leaf base (Radford et al., 1987). The leaves are deeply dissected, forming a basal rosette that can grow to a height of 0.6 to 1 meter. From the rosette, seed stalks extend, and the flowers, which can be pink, white, or lavender, have four petals (Figure 4). The fruits, known as siliques, resemble small bean pods. These siliques consist of two valves that separate seeds through a thin, papery septum (Harris & Harris, 2006).

Similar to the roots, the above-ground components of oil radish play a role in biofumigation. When incorporated into the soil, these plant tissues emit compounds that can aid in inhibiting specific soil-borne pests and diseases.

Figure 4. Oilseed radish flower (Anna Vinogradova, 2022).

3 OIL RADISH USE

3.1 Renovation crop

Renovation crop is a soil improvement plant that enhances soil health and structure. Oil radish can be cultivated primarily to address issues such as soil nutrient depletion, compaction and the most important the presence of pathogens.

The renovation plant/soil improvement plant compensation requirement can be fulfilled when it is sown in fields that have been cultivated with annual production plants in the previous year. Oil radish as a renovation plant can be sown by June 30 at the latest, and cannot be incorporated into the soil or chemically terminated at the earliest two months after sowing. Additionally, it is important to take into account that oil radish can be sown after sugar beets only if it fulfills requirements regarding restrictions of different pickling treatments (table 1) for the sowing of renovation plants after sugar beets (SjT & Sucros Oy, 2023).

Table 1. Sowing of renovation plants after different pickling treatments of sugar beets (SjT & Sucros Oy, 2023).

Sugar beet variety	Pickling treatment	Renovation plant permitted
Traditional	Force	yes
Conviso Smart	Force	no
Traditional	Cruiser	no
Conviso Smart	Cruiser	no
Traditional	Gaucho	no
Conviso Smart	Gaucho	no

In case of oil radish being not chemically terminated and left over winter until 15th April next year, it is considered as a cover crop, and farmer can get additional compensation of 50 euro per hectare in Finland (SjT & Sucros Oy, 2023). However, oil radish will naturally wilt and perish at temperatures as low as -6 degrees Celsius. The decomposition of the plants emits a noxious odor resembling that of rotten eggs.

3.1.1 Biofumigation

Oil radish functions as a natural fungicide and soil disinfectant against pathogens such as basal rot (*Sclerotium rolfsii*), white mold (*Sclerotinia sclerotiorum*), wire stem (*Rhizoctonia sp*.), charcoal rot (*Macrophomina phaseolina*), verticillium wilt (*Verticillium dahliea*), onion white rot (*Sclerotium cepivorum*) and soil pests such as nematodes (*Heterodera schachtii*). Biofumigation process includes suppression of soil-borne pests, weeds and soil diseases by compounds emitted from the *brassicae* crop that is mulched and incorporated into the soil (Evans, 2020).

The highest concentration of compounds called glucosinolates (GSLs) tends to occur at approximately 25% flowering, which is the recommended timing for incorporating biofumigants (Duff et al., 2020). Through the process of mulching and incorporation (figure 5), glucosinolates are released from the plant cells. Once released from plant cells and with the addition of irrigation water, glucosinolates are converted by the enzyme myrosinase into isothiocyanates (ITCs), gases that are toxic to various soilborne pathogens and pests. Irrigation and/or rolling helps to seal the gas in the soil so that they are the most effective in suppressing pathogens.

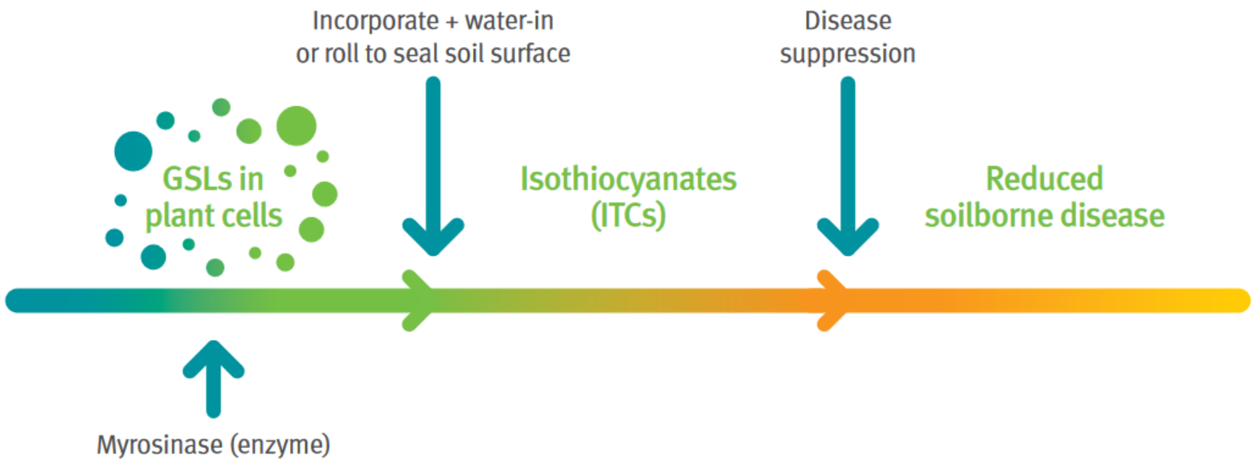

Figure 5. The Biofumigation process in *brassicae* plants (Duff et al., 2020).

The roots of oil radish release chemicals/compounds that are called glucosinolates, and they discourage the infestations of soil-borne diseases (Ngouajio and Mutch, 2004). Breakdown of glucosinolates in the soil results in compounds resembling the commercial soil fumigants such as Vapam® (*metham sodium*). Additionally, certain varieties of oil radish may also exhibit harmful effects on alien species of beetroot.

Although, plants-biofumigants have shown some activity against beneficial soil microorganisms in the laboratory such as *Trichoderma spp*. and *Bacillus amyloliquefaciens* (Duff et al., 2020). There are regional differences in biofumigation activity, pest, and diseases pressures and how they react to various growing seasons.

3.2 Catch crop

Serving as a catch crop, primary role of oil radish is to prevent the loss of valuable nutrients through leaching. It immobilizes significant quantities of nitrogen and phosphorus in its biomass, making them available in the following year's crop. Additionally, it effectively controls erosion during the winter months (McGill University, n.d.).

3.3 Underplant for a main crop

Oil radish, particularly during robust growth, has the potential to vie with the main crop for resources such as water, nutrients, and sunlight. The substantial taproot of oil radish can dive deeply into the soil, potentially surpassing shallow-rooted crops in nutrient competition. If not appropriately controlled, the dense foliage of oil radish may cast shade on the crops growing beneath it. Moreover, like all *brassicae* plants, oil radish releases compounds through its roots or tissues that can exhibit allelopathic effects. These compounds might hinder the germination or growth of nearby plants, including the main crop.

However, utilizing oil radish as an underplant for a crop is not permissible in Finland. The Finnish Food Authority does not approve of this combination if a farmer seeks a subsidy designated specifically for a land improvement plant (ruokavirasto.fi, 2023).

3.4 Forage crop

Although oil radish is not commonly cultivated explicitly for forage purposes like traditional forage crops such as alfalfa or clover. Oil radish's above-ground components, including leaves and stems, can serve as a forage resource for livestock under specific conditions.

Oil radish has the potential to yield up to five tons per hectare of high-quality above-ground biomass (Dean & Weil, 2009). The forage produced is highly digestible, making it suitable for grazing by all classes of livestock during both early and late seasons (Ngouajio & Mutch, 2004). However, due to forage immaturity consuming a very succulent crop can cause bloating in cattle by excessive retention of the gases of fermentation (Meerdink, n.d.). It is advisable to mix oil radish with a grass-legumes mixtures or supplement it with hay to reduce the risk of bloating and other health disorders in cattle (McCartney et al., 2009). For example, bloating in cattle can be observed within an hour after introduction to new forage or pasture with oil radish in pre-bloom stage.

Additionally, employing oil radish as a silage crop during its flowering stage is not advisable due to its pungency, which may be unfavorable for the ruminant system. However, using it in its pre-flowering stage may be considered acceptable.

3.5 Pest trap crop

Controlling insects in oil plants such as common pollen beetle (*Brassicogethes aeneus*) and flea beetles (*Phyllotreta spp.)* poses a challenge for farmers as effective insecticides are scarce (Skellern et al., 2023). The cultivation of oil radish may be employed as a companion plant within the field, serving as a decoy or trap plant to mitigate the impact of common pollen and flea beetles on *Brassicae* plants.

Flea beetles (Figure 6) manifest during the initial stages of plant development of oil plants, whereas common pollen beetles (Figure 7) emerge on plants during the blooming stage. When employing oil radish as a decoy plant, it is advisable for a farmer to sow it a few weeks in advance of the main *Brassicae* crop, facilitating the early initiation of blooming in the decoy crop.

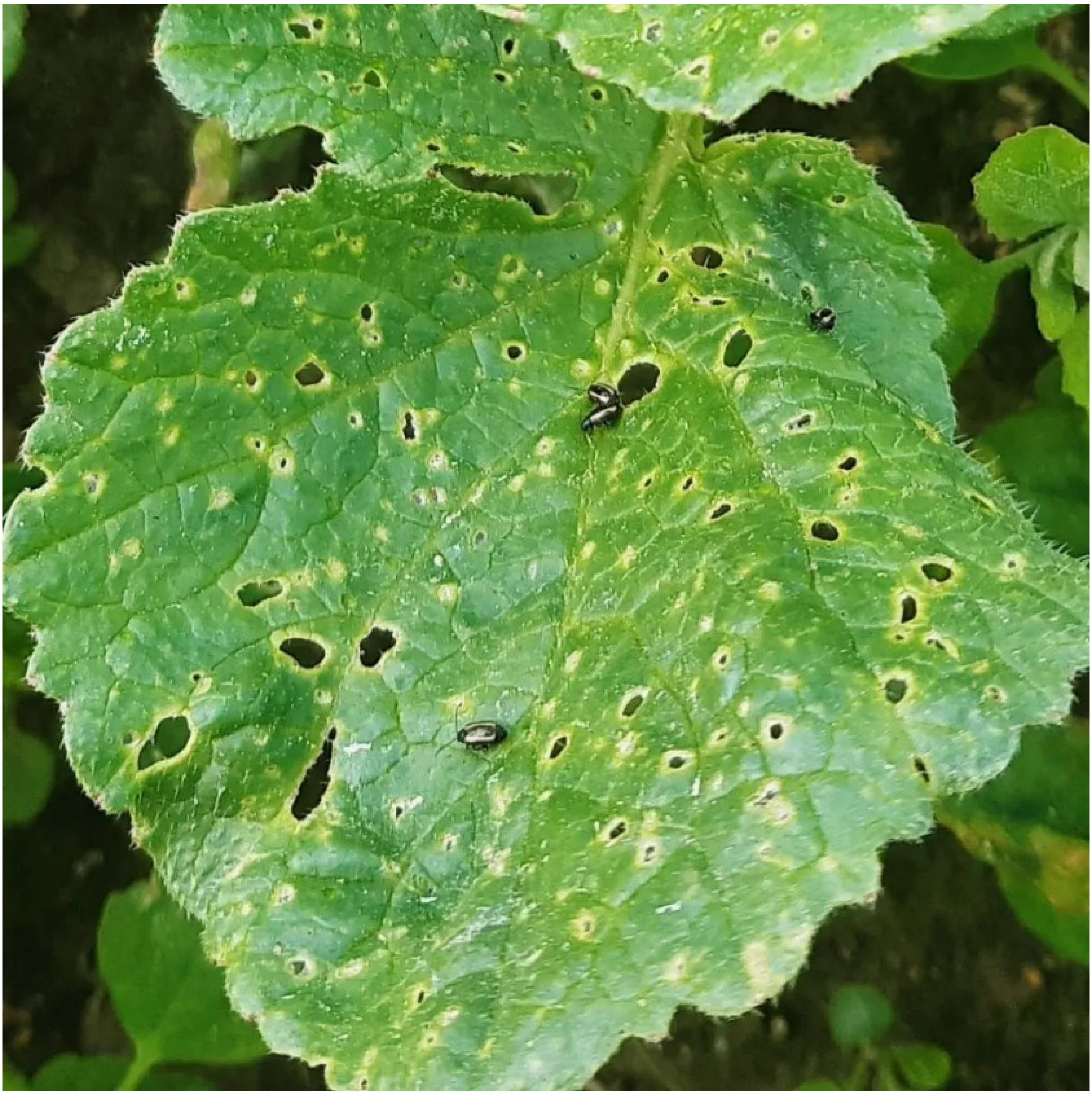

Figure 6. Stripped flea beetle (*Phyllotreta vittula*) damaging the oilseed radish leaf (Anna Vinogradova, 2022).

Figure 7. Common pollen beetle damaging the oilseed radish blooming flower (Anna Vinogradova, 2022).

3.6 Seed production

Oil radish is primarily a self-pollinating, although some cross-pollination may occur depending on the specific variety. Pollen transfer typically happens within the same plant, fostering genetic uniformity in the resulting seeds. Seed production takes place in the first or second year. As oil radish enters the reproductive phase, it produces flowers that develop into seed pods. Seed formation occurs as these pods mature, giving rise to viable seeds within them (Figure 8).

Figure 8. Oil radish maturing seedpods (Anna Vinogradova, 2022).

Seeds can be harvested when the pods transition from green to yellow or brown (Figure 9). The seedpods exhibit resistance to shattering and necessitate mechanical separation, often achieved with stationary threshers equipped with rollers to eliminate chaffy material (Navazio, 2007). Harvesting seeds (Figure 10) on a large-scale can be difficult. Using a combine for seed harvesting requires custom attachments. On average, one pound (or 0.45 kg) of seed comprises approximately 34,000 seeds (Midwest Cover Crops Council, 2012).

Figure 9. Oil radish mature seedpods. (Regionaal Landschap Rivierenland, n.d.)

Figure 10. Oil radish mature seeds. (Rasbak, n.d.).

3.7 Oil production

Oil radish is predominantly cultivated for its substantial taproot, which finds applications in various culinary uses. However, it differs from traditional oil crops such as sunflower or soybean. Although oil radish seeds do contain oil, they are not commonly grown on a large scale for oil extraction.

The oil content in oil radish seeds is generally lower when compared to traditional oil crops, containing approximately 30-40% oil by weight. The extracted oil from oil radish seeds encompasses a combination of fatty acids, including oleic acid, linoleic acid, and linolenic acid. The precise composition of fatty acids may vary based on factors such as seed variety and growing conditions.

According to De Andrade Avila & Sodre (2012) oil extracted from the seeds has been tested in Brazil and found to be an acceptable source of biodiesel. An important factor in the use of oil from the radish seed is its low viscosity, which improves engine performance, and it is an excellent oil to produce biodiesel (Faria et al., 2018). The average oil content in the seeds is 35% by mass and the yield is 1500 kg/ha, so when submitted to cold pressing, it provides an average of 284 l/ha of oil.

3.8 Oil radish as food

Forage radish or oilseed radish (*Raphanus sativus* var. *oleifera)*, is fit for consumption, with edible parts including young leaves, young flower clusters, seeds, and the taproot. The taproot is used in various culinary dishes. It can be consumed raw, sliced, or grated, in salads, or used in pickling. In some cuisines, it is also cooked in soups, stews, or stir-fries. The root of oil radish serves as a rich source of essential nutrients, vitamin C, and minerals. Additionally, it is low in calories and offers dietary fiber.

Oil radish, variety Japanese radish that also called daikon or tillage radish (*Raphanus sativus* var. *longipinnatus)*, has been cultivated as a food staple in Japan and China for many centuries (Whitbourne, 2023). It is also known as Chinese turnip or mullangi. It is round or cylinder-shaped. Most have white flesh, though some have green. It tastes slightly spicy and sweet but is milder than red radishes. Daikon has many varieties, including Minowase, Tama, and Miyashige white.

Daikon is an ingredient in traditional dishes, such as kayu and snegiri or kiriboshi (Yamaguchi and Okamoto, 1996). Farmers continue small-scale garden production and breeding of local landraces for seed production in the mountainous region of Kyushu (Yamaguchi & Okamoto, 1996). Oil radishes with different colored taproots are used for specific purposes and food types. Leaves are edible and sometimes eaten as mustard greens.

3.9 Oil radish in medicine

Oil radishes have a longstanding history of cultivation not only as a food crop but also as a renovating or soil improvement crop, leveraging their various medicinal actions for the benefit of the soil. Beyond their impact on soil health, oil radish also offers notable benefits for human health (table 2).

Oil radish, already thriving in every province of China, gained increased popularity and utilization in alternative medicine treatments when Zhang Xi Chun (1860-1933), a respected physician, emphasized the benefits of its seeds. Recognized as a cooling agent, historical applications of oil radish included treating inflammation, hypertension, and chronic tracheitis.

Owing to its diuretic properties, oil radish has been recommended for centuries in Asia as the treatment of kidney stones (New Directions Aromatics, n.d). The seeds naturally promote kidney flushing and detoxification, aiding in the breakdown of oxalic acid clumps and other hardened stones. Additionally, cosmetic produced from oil radish emollient and healing properties make it naturally beneficial for all hair and skin types healing acne, inflammations, and serving as an anti-aging remedy. It is advantageous for hands and can help strengthen nails, as well heal certain skin wounds such as mosquito bites.

Table 2. Medicinal use of oil seed radish (*Raphanus sativus oleiformis*) (Fern, n.d.).

Roots	Stimulate the appetite and digestion. Having a tonic and laxative effect upon the intestines and indirectly stimulating the flow of bile. Roots are best harvested before the plant flowers. Its use is not recommended if the stomach or intestines are inflamed.	Antiscorbutic, antispasmodic, astringent, cholagogue, digestive and diuretic.
	When crushed and used as a poultice for burns, bruises, and smelly feet.	
Leaves	Juice of the fresh leaves is diuretic and laxative.	
Seeds	Treatment of indigestion, abdominal bloating, wind, acid regurgitation, diarrhea, and bronchitis.	Carminative, diuretic, expectorant, laxative and stomachic.
Whole plant in general	Leaves, seeds and old roots are used in the treatment of asthma and other chest complaints. Consuming radish generally results in improved digestion, but some people are sensitive to its acridity and robust action. The plant is used in the treatment of intestinal parasites, though the part of the plant used is not specified. Oil radish inhibits the growth of Staphylococcus aureus, E. coli, streptococci, Pneumococci etc. All plant parts also show anti-tumour activity.	Raphanin, which is antibacterial and antifungal

4 IMPACT OF OIL RADISH ON THE SOIL

4.1 Soil structure

Oil radish has the capacity to enhance soil structure by breaking down soil particles and rendering it more crumble. It forms a distinctive taproot that can extend to depths of up to 180 centimeters. The upper 30 - 50 centimeters of the taproot thicken, reaching a diameter of up to 5 centimeters (Weil et al., 2006). This deep-rooting growth pattern is effective in addressing various resource concerns on cropland, particularly related to soil structure.

As the root undergoes decomposition, it creates substantial and deep pores in the soil. These voids facilitate the entry of water, air, and primary crop roots into the soil during the summer when it tends to be dry and compacted (Weil & Williams, 2004). The cultivation of oil radish can serve as a no-till option, providing an alternative to deep ploughing, mechanical tilling, and harrowing.

4.2 Nutrient cycling

Oil radish plays a crucial role in retaining essential nutrients within the soil, preventing their leaching. The capture and recycling of excess soil nutrients in its biomass represent a significant attribute of this catch crop. Through its deep taproot, oil radish has the capacity to absorb nitrogen residues in the soil from the preceding crop. Catch crops of oilseed/forage radish have the ability to absorb nitrogen in the range of 110 to 170 kg/ha (Weil et al., 2006).

While numerous catch crop species act as nitrogen scavengers, the roots of oil radish exhibit the capability to absorb nitrogen at more significant depths, thereby preventing its leaching into groundwater. In comparison to fields with red clover, ryegrass, and fallow fields, oil radish fields demonstrated lower levels of nitrate in soil gravitational water (Isse et al., 1999).

The roots of oil radish effectively absorb nitrogen from deeper soil layers, making it accessible in areas beyond the reach of the primary crop. The nitrogen sequestered in this manner becomes accessible to the subsequent crop during the decomposition of the oil radish plant in the spring. Cultivating oil radish serves as a natural fertilizer for the subsequent crop in the rotation, recycling nitrogen that might otherwise be lost through leaching (Kristensen & Thorup-Kristensen, 2004).

Furthermore, oil radish is capable to absorb and subsequently reduce of soil nitrate (NO3) concentration following fall manure application (figure 11). When considering various soils and methods of manure application, oil radish consistently exhibits significant NO3 uptake, leading to a substantial reduction of over 70% in NO3 concentration compared to control soil in manure-amended conditions (Ohio State University, 2008).

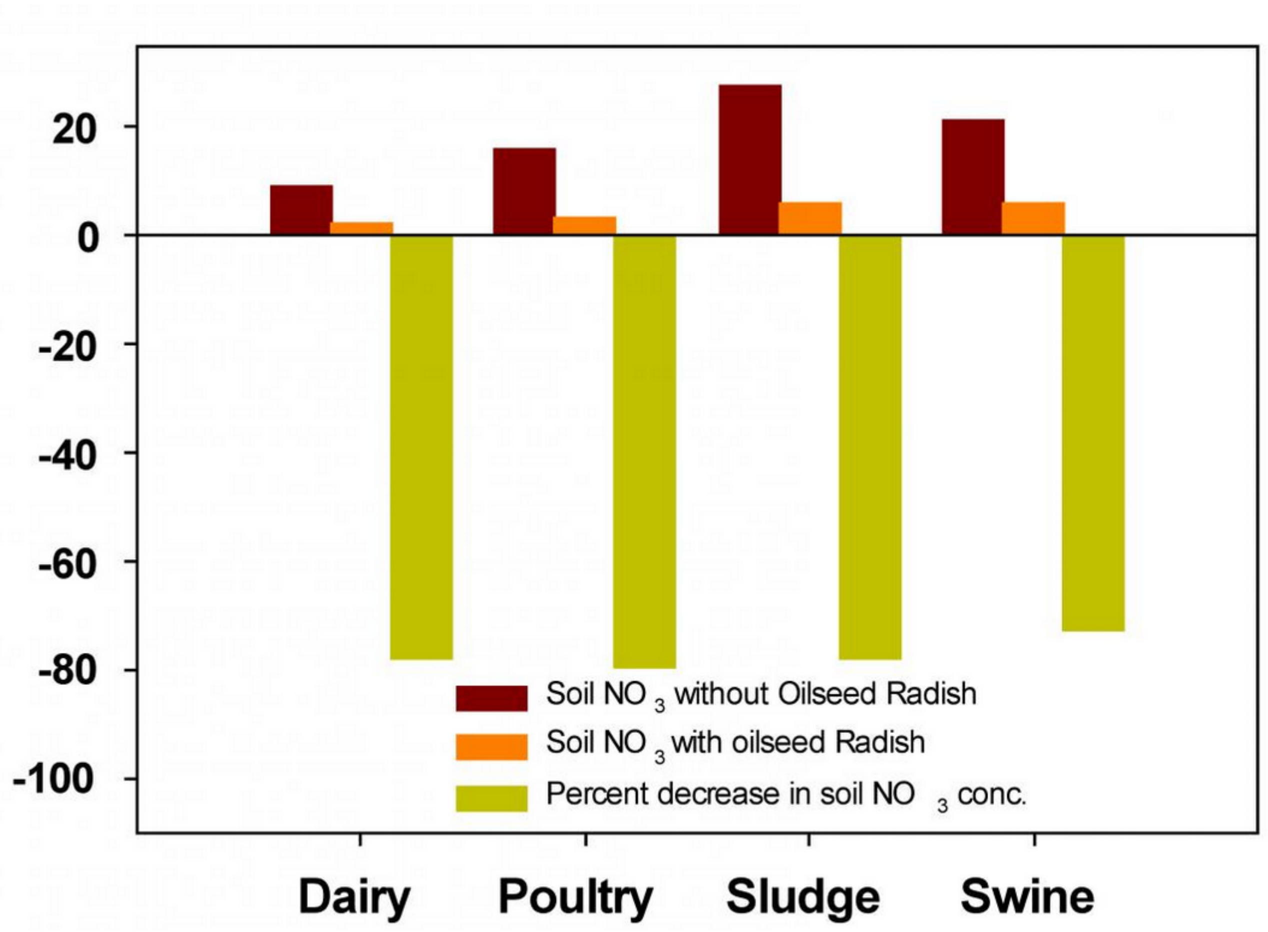

Figure 11. Absorption of soil nitrate (NO3) by oil radish (Ohio State University, 2008).

4.2.1 Oil radish decomposition

Due to its elevated water content, leading to a low carbon-to-nitrogen ratio, the plant material undergoes rapid decomposition. This decomposition results in the release of nutrients for the succeeding spring crop (Ohio State University, 2008).

If 10 percent of the biomass nutrients become available to the subsequent crop after decomposition in the upcoming spring, the utilized values would be as follows: nitrogen 70 kg/ha, phosphorus 15 kg/ha, potassium 120 kg/ha, and sulphur 15-20 kg.

5 OIL RADISH CULTIVATION

5.1 Cultivation requirements

Oil radish thrives when situated in a sunny environment, and can grow on all types of soil. Fertile, well-drained, deep, sandy, slightly acidic soils, rich in organic matter would fit for best growth, and oil radish planted in heavy, or clay soils will grow slower and may have misshapen or deformed roots. Plants are susceptible to drought and require irrigation during dry spells in the summer or the root quality will rapidly deteriorate, and the plant will go to seed. Oil radish prefers a pH in the range 6 - 6.5, tolerating 5 - 7.5 (Fern, n.d.).

Oil radish thrives in regions with annual daytime temperatures ranging from 12 to 25°C, although it can tolerate temperatures between 5 and 30°C. The plant is ideally suited to locations with a mean annual rainfall between 800 and 1000 mm, yet it can endure rainfall levels ranging from 500 to 1500 mm (Fern, n.d.).

5.2 Sowing

The soil tillage for oil radish is similar to the preparation for cereal grains (Canadian Organic Growers, 1992). When oil radish follows the harvest of a cereal crop or early maturing crops such as vegetables in the crop rotation, it is essential to thoroughly work the soil by plowing and harrowing. If needed the soil can be rolled after seeding.

Finnish seed operator Naturcom (n.d.) recommends seeding oilseed radish and tillage radish or daikon to a depth of 1–2 cm separately or in a mixture with rows spacing 10 to 25 cm. For example, they can be seeded with other soil improvement plants with seeding rate of 5–10 kg/ha in mixtures, or separately 15–20 kg/ha.

5.3 Fertilizing

Oil radish can be fertilized in accordance with the nitrate and phosphorus regulations as any commercial *brassicae* crop (table 3, table 4 and table 5). Fertilizers are usually not required or simply are not necessary as it is itself can appear to be a nutrient catching crop.

Although, if the crop rotation includes to mulch and incorporate the oil radish vegetation after the two-month minimum period, and the growth conditions are optimal, a stimuli fertilizing can be recommended to reinforce plants growth and development.

Table 3. Tillage Radish nutrient uptake (kg/ha) (Duff et al., 2020)

Biomass (fresh weight), t/ha	**Nitrogen (N), kg/ha**	**Phosphorus (P), kg/ha**	**Potassium (K), kg/ha**	**Sulphur (S), kg/ha**
158	390	59	457	114
146	458	69	463	89

Table 4. Nitrogen (N) fertilizing recommendations for renovation plants based on organic matter (%) in the soil (SjT & Sucros Oy, 2018).

Organic matter %	0-3	6-12	12-20	20+
Nitrogen (N) kg/ha/year	60	60	60	60

Table 5. Phosphorus (P) fertilizing recommendations for renovation plants based on current fertility class of the soil (SjT & Sucros Oy, 2018).

Fertility quality	Low	Lower	Acceptable	Satisfactory	Good	High	Very high
Phosphorus (P) kg/ha/year	20	16	12	7	-	-	-

Biofumigants have high requirements for nitrogen and potassium as well as sulphur, as the glucosinolates are sulphur containing compounds. However, when fully mulched and incorporated into the soil, any applied nutrients will be available through nutrient cycling for future crops (Duff et al., 2020).

5.4 Mulching and incorporation

The ideal timing for mulching and incorporation of oil radish as a biofumigant is when the crop is at early to mid-flowering when the foliage is still succulent (Evans, 2020). Additionally, irrigation is recommended prior to mulching and incorporation if soils are below 50% of field capacity.

The soil moisture level should ideally range between 75% and 100%—sufficiently moist but not too sodden. Achieving the correct moisture content is crucial, to the extent that irrigation should be contemplated if the necessary equipment is accessible, rather than risking crop loss due to unfavorable conditions. Soil temperatures should exceed 10°C to optimize the dispersion of volatile gases throughout the soil following incorporation.

According to Duff et al. (2020) the efficacy of biofumigants against identified pathogens was assessed across different incorporation techniques (figure 12). Overall, all incorporation methods demonstrated effective performance against the known pathogens, albeit with a few exceptions. Strip tillage exhibited the highest variability in biofumigant efficacy. Mulch/rotary, hoe/irrigation and mulch/disc, plough/irrigation displayed similar levels of biofumigant effectiveness. Additionally, there was minimal disparity observed between irrigation and rolling post-incorporation.

Pathogen	Fallow (Field control)	Mulch + Disc plough + Irrigation	Mulch + Disc plough + Roll	Mulch + Rotary hoe + Irrigation	Mulch + Rotary hoe + Roll	Mulch + Strip till implement + Irrigation
Sclerotium rolfsii (basal rot)	•••••	•••••	••••	•••••	•••••	•••••
Sclerotinia sclerotiorum (white mould)	••••	•••	••••	••••	••••	•••
Rhizoctonia sp. (wire stem)	•••••	•••••	•••	••••	•••••	••••
Macrophomina phaseolina (charcoal rot)	••••	••••	•••	•••	••	••
Verticillium dahliea (verticillium wilt)	•••••	••••	••••	•••••	•••••	••••
Sclerotium cepivorum (onion white rot)	••••	••••	••••	••••	••••	•••

Legend: Percentage mortality

•	0–20
••	21–40
•••	41–60
••••	61–80
•••••	81–100

Figure 12. The extent of pathogen mortality after different methods of incorporation (Duff et al., 2020).

5.5 Crop protection

Oil radish as a biofumigant-plant or renovation plant generally does not require intensive crop protection management for various reasons, and may be considered economically unfeasible (Duff et al., 2020). Oil radish is flexible, fast-growing, disease disinfecting plant that can reach maturity in under 60 days, achieving a height of two meters within 6-8 weeks (McGill University, n.d.). Its rapid and robust growth results in substantial shading and competes effectively with weeds for space. It is possible to obtain almost a dozen of tons of green matter per hectare after just 45 days.

In optimal conditions, oil radish seedlings can emerge as soon as three days after planting, and provide full canopy cover effectively shading out weeds within 3-4 weeks (Weil et al., 2006). Studies in Michigan found that oil radish reduced weed biomass by 4500 kg/ha when compared to a fallow site (Snapp and Mutch, 2003). The biomass decomposes rapidly, leaving the seedbed prepared for planting without requiring tillage or residue removal. The prevalence of flowering weeds is likely to be less in the year following oil radish cultivation.

6 FIELD EXPERIMENT

The field experiment took place in the summer 2023 at the Campus field of Seinäjoki University of Applied Sciences. Oilseed radish (*Raphanus sativus oleifera* variety *Valencia*) was planted in a mixture with other annual soil-improvement plants, including white sweet clover (*Melilotus albus*) and yellow sweet clover (*Melilotus officinalis*). The aim of the experiment was to evaluate the impact of mulching on the recovery of oilseed radish and its root development two months after sowing or during oilseed radish flowering stage.

6.1 Materials and methods

The research took place in the field with the soil type of fine sand moraine, categorized as mineral soils. The organic matter content in the field ranges from 20 to 40%. A soil sample was collected from the field in autumn 2021, revealing a good pH level of 6.5. Phosphorus, potassium, magnesium, and sulphur were found to be at a good level based on the soil analysis. Calcium was determined to be at an acceptable level.

The field was plowed and harrowed and then three small plots of 10 m^2 each were established in the field. Each plot was mechanically removed from weeds and irrigated with approximately 35 liters of water as the weather stood hot and dry. Plant growth was observed and photographed approximately every two weeks (figure 13).

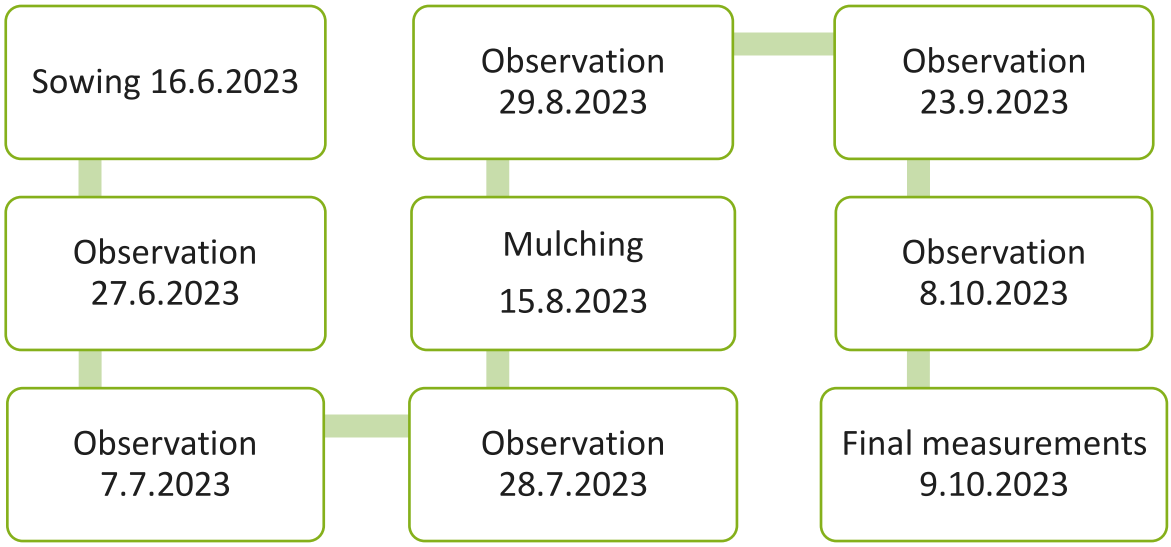

Figure 13. Timetable of the actions of the field experiment

Oilseed radish and sweet clover were sown by hand in rows spaced 20 cm apart on 16th June 2023. Oilseed radish seeding rate was 10 kg/ha in a mixture with sweet clover with seeding rate of 7 kg/ha. Fertilizers were not used in this experiment. The late sowing of oilseed radish was intentional, aiming to coincide with the soil reaching its optimal temperature for accelerated growth. Additionally, this timing could potentially reduce the plant vulnerability to insect damage.

On 15th August, first measurements were conducted on 0.25 m^2 within each plot to evaluate the biomass of the plants. Subsequently the dry matter kg/ha of oilseed radish was calculated to determine the rate of development in each plot (table 6).

On 9th of October, final measurements were taken on 0.25 m^2 in each plot within sections A and B to assess the biomass of oilseed radish plant and its roots. Sections 1A to 3A contained the biomass of non-mulched oilseed radish plant parts and its roots, while Sections 1B to 3B contained the biomass of mulched oilseed radish plant parts and its roots. The biomass of each section was weighed, dried, and calculated into dry matter kg/ha.

6.2 Observations of the vegetation

On the first observation on 27th June, the initial growth of oilseed radish plants was rapid but not even. Some areas of the experimental plots remained empty while some specimens had already started to sprout. Flea beetles-induced holes could be observed, although they were not significantly detrimental as many leaves remained untouched (Figure 14) By mid-June, flea beetles had possibly finished their initial life cycle and were no longer actively damaging the oilseed radish.

Figure 14. Observation on 27th June 2023. Oilseed radish being damaged by flea beetles during its initial stage of growth and development (Anna Vinogradova, 2023).

However, during the early stages of oilseed radish growth, weeds quickly proliferated in the area (Figure 15), mainly including white goosefoot (*Chenopodium album*), scentless mayweed (*Tripleurospermum inodorum*), plume thistle (*Cirsium*), dandelion (*Taraxacum*), and couch grass (*Elymus repens*). This wave of weeds covering the plots was manually removed, allowing the oilseed radish to reach its full height and create shade that hindered further weed growth.

Figure 15. Observation on 27th June 2023. White goosefoot (Chenopodium album) and other weed species covered the plot (Anna Vinogradova, 2023).

On 7th July, it was observed that sweet clover took longer to germinate (Figure 16), which later indicated its inability to compete with oilseed radish in terms of equal growth and development rate. It was overshadowed by the oilseed radish's foliage, impeding its growth.

Figure 16. Observation on 7th July 2023. The initial emergence of sweet clover from the soil began (Anna Vinogradova, 2023).

On 15th August, each plot was divided into two sections marked as A and B. The section B with oilseed radish at flowering stage was cut to 10 cm above the ground, while plot A was left undisturbed to allow continued growth (Figure 17).

Figure 17. Half of the plots are being mulched on 15th August 2023 (Anna Vinogradova, 2023).

During the observation on 29th August, section B with mulched oilseed radish did not wilt but continued to grow, and already had quite large leaves on the stems (Figure 18).

Figure 18. Observation on 29th August 2023. Mulched Oilseed radish continued to grow (Anna Vinogradova, 2023).

On the second last observation on 23rd September, section A, where the oilseed radish was left to grow freely, had reached a height of over two meters, and started to lean over to the sides of the plot due to its own weight (Figure 19), while section B has entered the flowering stage.

Figure 19. Observation on 23rd September 2023. Section B with mulched oilseed radish has entered the flowering stage (Anna Vinogradova, 2023).

6.3 Results and discussion

At the moment of mulching the average values for all plots combined were a biomass of 683,7 fresh weight g/m^2 and biomass of 1018 dry matter kg/ha. Plot 2 had the highest amount of plant fresh weight g/m^2 per plot and dry matter kg/ha, and more dense vegetation compared to the Plot 1 and 3 (table 6). Plot 2 had a biomass of 748 fresh weight g/m^2 with dry matter percentage of 17% and a biomass of 1272 dry matter kg/ha, while Plot 3 had a biomass of 719 fresh weight g/m^2 with a dry matter percentage of 11% and a biomass of 791 dry matter kg/ha, and Plot 1 had a biomass of 584 fresh weight g/m^2 with a dry matter percentage of 17% and a biomass of 993 dry matter kg/ha.

Table 6. Biomass measurements of the oilseed radish before mulching on 15th August. Plants.

Date	Plot	Biomass (fresh weight), g/m2	Biomass (fresh weight) g/plant	Dry Matter (%)	Biomass (Dry Matter) kg/ha
15.8.2023	1	584	157.42	17%	993
	2	748	170.64	17%	1272
	3	719	103.01	11%	791
	Average	683.67	143.69		1018

On 9th of October, final measurements of plant biomass and roots biomass from each plot were taken. Each plot and each section underwent measurement for fresh weight, however, only sample from Plot 2 Section A and sample from Section B underwent measurement for dry matter content. It was decided so due to the denser vegetation at the moment of mulching and Plot 2 was considered as leading plot.

The results showed (table 7) that biomass of fresh plant parts above soil surface of the oilseed radish from Section A with mulched oilseed radish had on average a biomass of 5005 fresh weight g/m^2 with dry matter percentage of 13% and a biomass of 6506 dry matter kg/ha, while oilseed radish from Section B with non-mulched oilseed radish had on average a biomass of 1235 fresh weight g/m^2 with dry matter percentage of 12% and a biomass of 1482 dry matter kg/ha. The difference in the amount of dry matter kg/ha of plant part above soil surface of the oilseed radish between sections A and B on 9th of October was in total 4006 of dry matter kg/ha.

Table 7. Biomass of plant part above soil surface of the oilseed radish on 9th of October. (Section A =not mulched in August, section B = mulched in August)

Date	Section and plot	Biomass (fresh weight), g/m2	Dry Matter (%)	Biomass (Dry Matter) kg/ha
8.10.2023	A1	7588		
	A2	4430	13%	5759
	A3	2996		
	Average	5005	13%	6506
	B1	1343		
	B2	1000	12%	1200
	B3	1362		
	Average	1235	12%	1482

The roots from all three plots were also weighted and their lengths was measured (table 8). The roots from Section A with non-mulched oilseed radish that was uninterruptedly growing from 16th June to 9th October (116 days) were on average 10 cm longer than the roots from Section B with oilseed radish being mulched (Figure 20, Figure 21 and 22).

The longest and thickest tap root reaching 36 cm was from Plot 2 Section A and had a biomass of 988 fresh weight g/m^2 with a dry matter percentage of 7% and a biomass of 692 dry matter kg/ha, while the tap root from Plot 2 Section B was reaching 25 cm had a biomass of 539 fresh weight g/m^2 with a dry matter percentage of 17% and a biomass of 916 dry matter kg/ha.

Altogether the tap roots from Section A had an average biomass fresh weight of 863 g/m^2 with dry matter percentage of 7% and a biomass of 604 of dry matter kg/ha. The average tap root length from Section A was 31 cm. The tap roots from Section B had an average biomass fresh weight of 443 g/m^2 with dry matter percentage of 17% and a biomass of 753 of dry matter kg/ha. The average tap root length from Section B was 22 cm. The difference in the amount of dry matter kg/ha of plant part above soil surface of the oilseed radish together with tap roots between sections A and B on 9th of October was in total 3857 of dry matter kg/ha.

Table 8. Biomass of tap roots of the oilseed radish on 9th of October (Section A = not mulched in August, section B = mulched in August)

Date	Section and plot	Biomass (fresh weight), g/m2	Biomass (fresh weight) g/root	Dry Matter (%)	Biomass (Dry Matter) kg/ha	Taproot length cm
8.10.2023	A1	990				30
	A2	988	470.8	7%	692	36
	A3	612				27
	Average	863.33	470.80	7%	604	31
	B1	452				20
	B2	539	181.24	17%	916	25
	B3	338				21
	Average	443.00	181.24	17%	753	22

Figure 20. Oilseed radish roots from Plot 1 Section A & B (Anna Vinogradova, 2023).

Figure 21. Oilseed radish roots from Plot 2 Section A & B (Anna Vinogradova, 2023).

Figure 22. Oilseed radish roots from Plot 3 Section A & B (Anna Vinogradova, 2023).

Although the pictures and tables suggest that Section A has developed more robust roots than Section B, it remains uncertain whether mulching is the sole factor contributing to this discrepancy. Due to the narrower size of the experimental plots compared to the sowing machine, manual sowing was necessary. When seeds are sown manually, particularly small ones like oilseed radish and sweet clover, precision is crucial. Variations in sowing depth or seed spacing may occur, impacting the emergence of seedlings depending on their placement and the moisture level they encounter.

Furthermore, at the time of sowing, the soil of completed plots was relatively dry due to prolonged dry days in early June (table 9), featured uneven surfaces, and were infested with weeds. Some plants may have suffered from inadequate moisture, or weeds that weren't entirely eradicated may have displaced oilseed radish and sweet clover seeds to the surface. Additionally, weather conditions significantly influenced plant growth. While June and July were warm with moderate rainfall, allowing for optimal plant development, by mid-August, when the oilseed radishes were mulched, Finland experienced heavy rainfall that persisted until late October. This undoubtedly impacted the second growth of mulched oilseed radish. Due to these factors, plant growth was inconsistent, with some plants germinating earlier than others. Consequently, some roots exhibited larger and denser growth, while others were thin and partly deformed.

Table 9. Weather information (ATU 2023, Average temperature 2023, Precipitation amount 2023, Average temperature 2011-2020 and Precipitation amount 2011-2020) from the closest weather station, Seinäjoki Pelmaa (Finnish Meteorological Institute).

Month	Accumulated Thermal Unit, C° 2023	Average temperature, C° 2023	Average temperature, C° 2011-2020	Precipitation amount, mm 2023	Precipitation amount, mm 2011–2020
June	305.2	15.7	21.4	23	51.8
July	336.05	15.9	16.9	117.3	69.9
August	355.2	16.3	15.2	138.2	88
September	259.75	13.5	10.8	90.7	59.5
October	-99.7	1.4	4.6	58.9	56.6

Nevertheless, one can infer that the experiment achieved partial success despite the challenging conditions faced by the oilseed radish. It demonstrated greater success in long-term root growth compared to the mulched counterpart. The development of long roots by oilseed radish can create deeper holes and pores in the soil, facilitating better aeration and water infiltration. Additionally, thicker roots can further enhance the soil's structure by exerting pressure on the surrounding soil particles, promoting aggregation and stability. Overall, these root characteristics play a vital role in improving soil porosity, water retention, and nutrient availability, ultimately contributing to the overall health and productivity of the soil.

7 CONCLUSIONS

The Field Experiment 2024 showed that the total biomass of non-mulched oilseed radish differed significantly from the total biomass of mulched oilseed radish. Root analysis provided intriguing information about root morphology and biomass distribution, where roots from Section A with non-mulched oilseed radishes, were on average longer and thicker than roots from Section B with mulched oilseed radishes, but had a lower percentage of dry matter. This section difference suggests a complex interaction between mulching practices, soil conditions, and root physiology, warranting further investigation into the mechanisms underlying these differences.

In addition, environmental conditions and the hand seeding process introduced additional challenges to the experiment. Despite these problems, the experiment demonstrated partial success. The development of longer, thicker roots can significantly impact soil structure by increasing porosity, water retention, and nutrient availability. These results convincingly demonstrated the important role of non-mulched oilseed radish and potential positive impact on soil structure and fertility, as a soil improvement crop, and its potential contribution to sustainable agricultural practices.

In conclusion, it would be recommended further research, for example, on long-term effects of mulched oilseed radish on soil health parameters such as microbial activity and soil pathogens, soil organic matter content, and nutrient availability. Understanding how different microbial populations respond to mulching and root exudates in oilseed radish may provide more information about plant-soil interactions, and establish basis for strategies for using oilseed radish as a soil improvement or renovation plant in crop rotation.

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