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Master thesis

INTERCROPPING CEREALS WITH RYEGRASS AND OTHER CROPS FOR IMPROVED DIVERSITY: RESULTS FROM A TWO YEAR'S TRIAL AT INNLANDET, NORWAY

Underkultur i korn ved og bruk av raigras og andre vekster for økt diversifisering: resultater fra et toårig forsøk i Innlandet, Norge.

Applied Ecology

June 2022

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“Alone we can do so little, together we can do so much”, a statement quoted by Helen Keller has been the most relevant quote for my two years’ work during which many great helping hands have accompanied me. The thesis in the present form is the outcome of their synergistic effort, and I owe all of them a debt of gratitude. Thus, I would like to extend my immense pleasure and profound acknowledgement to all those remarkable persons and institutions whose continuous help has energised me to work out this thesis monograph.

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Prabhat Poudel

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ACRONYMS

˚C	Degree on the Celsius scale
C	Carbon
cm	Centimetre
CV	Coefficient of Variance
daa	One-tenth of a hectare, a Norwegian land measurement unit
ha	Hectare
K	Potassium
kg	Kilogram
km	Kilometre
LSD	Least significant difference
masl	metres above sea level
mg	milligram
mm	millimetre
N	Nitrogen
NLR	Norwegian agricultural extension service
NO_3	Nitrate
ns	Non-significant
P	Phosphorus
SEm	Standard error of the mean
SOC	Soil Organic Carbon
Yr	year

ABSTRACT

Cover crops are companion crops that can be grown together or in between main crops, e.g. cereals, to get ecological benefits and increase diversity. An experiment was conducted at the research station at Innlandet University College, Blæstad, Ridabu, Norway, to examine the effect of various cover crops on the performance of cereals and their ecological services. The trials were conducted from May to September 2019 and from April to August 2020. The experimental units were laid out as a split-plot design with spring-wheat cv. 'Mirakel' and barley cv. 'Salome' as the main crops and Italian ryegrass, perennial ryegrass and meadow fescue as cover crops (on sub-plots). Each cover crop was sown at the same time and two weeks after sowing the wheat and barley, along with a control plot, making seven subplot treatments, and each treatment was replicated thrice. There was no significant difference in grain yield of the main crops under different cover crops. The cover crop grew well after harvesting the cereals, and the cover crop growth was better in wheat than in barley. The Italian ryegrass sown on the same day as cereal crops had the highest biomass production, whereas meadow fescue had the lowest growth. The weed was significantly lowest under Italian ryegrass sown on the same day as the cereal crops. The cover crop did not affect the yield of cereal crops, which indicated that cover crops could be successfully cultivated with cereal crops without significant reduction in grain yield, along with the ecological services of the cover crops, such as weed suppression and organic matter addition and increased diversity.

Norwegian abstract

Underkulturer og fangvekster er vekster som kan dyrkes sammen med korn for å gi økologiske fordeler og øke diversiteten. Med mål om å undersøke effekten av forskjellige underkulturer, ble et det i løpet av mai til september 2019 og april til august 2020 gjennomført et feltforsøk hos Høgskolen i Innlandet, Blæstad, Ridabu, Norge. Forsøksleddene ble lagt ut som et split-plot design med vårhvete cv. 'Mirakel' og bygg cv. 'Salome' på stor-ruter og italiensk raigras, flerårig raigras og engsvingel som underkulturer (fangvekster) på småruter. Hver underkultur ble sådd samtidig eller to uker etter såing av hvete og bygg, og sammen med en kontroll, så ble det sju forsøksledd på småruter. Hver behandling ble gjentatt tre ganger. Resultatene viste ingen signifikant forskjell i kornavling under ulike underkulturer. Italienske raigras sådd på samme dag som kornet ga best underkulturvekst, mens engsvingel ga lavest vekst. Ugraset var betydelig lavere med italiensk raigras sådd på samme dag med kornet enn de andre underkultur-leddene. Avlingen av underkultur påvirket ikke utbyttet i form av kornavlinger, noe som indikerte at underkultur med fordel kan benyttes ammen med korn uten betydelig reduksjon i kornutbyttet, samtidig som de økologiske tjenestene til underkulturen ivaretas, som reduksjon av ugras, økt produksjon av organisk materiale og økt diversitet.

1 INTRODUCTION

Wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) are the dominant crops in the world's cereal-based cropping systems. Cereals are the cultivated annual grasses belonging to the family Poaceae for the consumption of the components of their grain. More than 50% of calories consumed by humans and livestock comes from cereal grains (Cereal Grains, 2022). Cereal crops constitute a significant portion of the human diet, and there are several health benefits (Yasmin, 2017). They are important source of carbohydrates and fibres, proteins, vitamins and other micronutrients (McKevith, 2004). They play a major beneficial role in protecting from heart diseases, diabetes, bowel diseases and cancer as well (Cereals and Wholegrain Foods, 2020). World cereal production in 2021 is 2796 million tons, with an increment of 0.7% from that of 2020 (FAO, 2022). In Norway, cereal production in 2018 was 678,543 metric tons, the average cereal yield was 2,430 kg per hectare, and land under cereal cultivation was 279,238 hectares (Knoema, 2018). The growth of cereals depends on the amount of rainfall, soil conditions and the agronomic practices applied to the crop. The widely grown cereals in the world are wheat, maise, rice, barley and oats. In Norwegian cereal production, barley is the most widely grown that constitutes about 45% land of total cereal production (Graminor, n.d.). Barley constitutes 145 thousand hectares of land, and 600 thousand ton production, whereas wheat constitutes 80 thousand hectares of land and 420 thousand ton production in Norway (World Data Atlas, 2020).

Cover crops are the crops grown for the protection and enrichment of the soil. Cover crops improve the physical and biological properties of soil and hence prevent the nutrients from leaching as well as soil erosion. Cover crops supply nutrients to the soil, break the pest cycle, improve soil water availability, improve water infiltration, suppress weeds as cover crops out-compete weeds for the resources and maintain overall soil health (USDA, n.d.). Cover crops provide several ecosystem services and help mitigate the effects of climate change (Neault, 2021). There are four classes of cover crops. Grasses include crops like Perennial ryegrass (*Lolium perenne*), Italian ryegrass (*Lolium multiflorum*), Meadow fescue (*Festuca pratensis*), Oats (*Avena sativa*), whereas legumes include crops like White clover (*Trifolium repens*), Alfalfa (*Medicago sativa*), brassicas include crops like Radish (*Raphanus sativus*), White mustard

(*Sinapis alba*), Turnip (*Brassica rapa*) and non-legume broadleaves include crops like Spinach (*Spinacia oleracea*), Flax (*Linum usitatissimum*).

Cereals are found in specific regions and grasslands in others, which contrasts with the mixed farms typical in the 19th century onward, where grassland and cereals were grown in rotation. Productivity has indeed increased, but as many would argue on, the costs of soil fertility and agro-biodiversity. Continuous monoculture of barley and wheat is practised mainly in Norwegian conditions. Because of repeated use of the soil nutrients by growing the same crop, these nutrients decline, thereby crop production. Mono-cropping also creates the spread of pests and disease, which leads to a decline in cereal production. Cover cropping breaks the continuous cycle of mono-cropping. Though there are many long term benefits of cover crops, the use of cover crops in cereals is found to be less among Norwegian growers (Neault, 2021).

Heavy rainfall in autumn and heavy snowmelt in spring is responsible for leaching and soil erosion in Norway (Arnoldussen, 2000). Grasses are considered an excellent choice to use as a cover crop to rummage nutrients from the soil left from the previous crop (Mosaic, 2022). When the nutrients are not scavenged, they are likely to be subjected to leaching. When grasses decompose in the soil, their residues tend to last longer than other classes of cover crops because of the high C present in grasses and also, they tend to produce a large number of residues. Grasses suppress the weeds as well as improve the soil's organic matter. Also, grass-based livestock production is mainly focused in Norway (Nibio, 2020).

The cover crops can be sown easily with main crops as forage crops. This is a well-established cultivation method among livestock farmers, and with the corresponding seeding technology available. The main challenge is to make a balance between the main crop and the cover crop, to avoid competition but at the same time establish a cover crop during the growth of the main crop. The use of cover crops can successfully be used to prevent N and P from reaching waterways through run-off, leaching or erosion, and a compilation of Nordic studies shows that N leaching is approximately halved with the use of ryegrasses (Aronsson et al. 2016). Higher precipitation in autumn (Hanssen et al. 2015) may reduce trafficability, postpone threshing, and eventually reduce cereal quality and yield loss (Sogn and Hauge 1976). Studies indicate that cover crops may counteract this by increasing aggregate stability and by the stabilising effects of the living roots themselves (Faucon et al., 2017). We will produce information on how selected cover crops affect soil aggregation, field trafficability, cereal yields, and quality. Cover cropping may be a way to improve soil quality and cereal yields in the long run, but short term economic results count for the farmer.

The current study assesses the effect of cover cropping by grasses and their sowing time on wheat and barley in Norway. The study will serve as a reference and guideline to the government, non-government organisations and other stakeholders involved in cereal production. Hence, the current study was carried out with the following objectives:

- To assess the growth and production of various cover crops at the different dates of sowing
- To examine the effect of cover cropping on weed growth and yield of cereal crops, i.e. wheat and barley

2 LITERATURE REVIEW

In this chapter, an effort has been made to briefly review the research findings available on the topics relevant to the current experiment.

2.1 Cover crops

The plants that are planted along with the main crops or after the main crop and are killed before the plantation of the next crop are known as cover crops (Merfield, 2019). Cover crops can be green manures, which are nitrogen-fixing leguminous plants that provide nitrogen to the crops grown in the field. Cover crops can also be catch crops grown during the fallow period to protect nutrient losses from the field. Sometimes cover crops can also be living mulch that can be grown along with the main crop or after the main crop to suppress weed competition and protect leaching of nutrients (Hatfield & Sauer, 2020). Cover crops are highly beneficial to the agricultural systems as they contribute to sustainable production by controlling soil erosion, enhancing soil quality, conserving soil moisture, and suppressing weeds, disease-causing pathogens, and pests harbouring in agricultural crops (Hartwig & Ammon, 2002a).

Cover crops are grown worldwide, whereas winter annuals as cover crops are the most common type in northern temperate regions. These annuals are either grown during the off-season winter months. There are also summer annuals or perennials used as cover crops grown during all cropping seasons (Lu et al., 2000). Integration of cover crops in the orchards, vineyards, and fields of agronomic crops like wheat, barley, corn, and forages have worked out in the agricultural systems (Hartwig & Ammon, 2002b). In the European region, the crops produced such as grain production Wheat, Oats, Barley, Rye, and Triticale production or oilseeds crops like (*Brassica napus* L. subsp. *napus*) and, to some extent turnip rape (*Brassica rapa* subsp. *oleifera*) or the legumes crops like pea (*Pisum sativum* L.) and broad bean (*Vicia faba* L.), etc. are annual plants which are either cultivated in spring (spring type) or autumn (winter type). Even though the farmers follow different crop rotation practices, there lies a period during which the field remains fallow. Under such conditions, there is neither active plant growth nor uptake of nutrients. Thus, cover crop planting is suitable during the long interval between summer harvest and the sowing of spring crops. Such long intervals usually occur in temperate European regions. However, seeding of a cover crop can be suitable between the time period of the summer harvest and the sowing of the winter crops (Büchi et al., 2018). Usually, after the main crop is harvested, the cover crops are established. However, cover crops can also be sown before the sowing of the main crop or at the same time as the main crop (Carof et al., 2007). For instance, perennial cover crops are incorporated before the winter seasons in the northern temperate areas to reduce the negative effect of low soil mineral nitrogen content occurring due to the sowing of main crops in the spring season (Tonitto et al., 2006). The cover cropping system plays a very crucial role in the sustainable food production system, but careful consideration regarding the choice of cover crop species, timing of cover crop planting and kill, method of kill and degree of tillage should be taken while selecting and sowing cover crops in order to derive optimum benefits from the cover crops (Lu et al., 2000).

2.2 Ecosystem Services of Cover Crop

The ecosystem services of cover crops contribute sustainably to the environment, either in sole cropping or mixed cropping (Lamichhane & Alletto, 2022). Cover crops have the beneficial practice of accretion of soil organic matter. They have gained attention in mycorrhizal fungi inoculation in the soil, reducing early weeds and soil pathogens. Cover crops reduce soil compaction, improve structural and hydraulic properties of the soil, balance soil temperature, improve microbial properties, recycle nutrients, suppress weeds, and are involved in climate regulation and water and air quality regulation(Blanco-Canqui et al., 2015).

2.2.1 Sequestering soil organic C

Cover crops influence the pathways of gains and losses of organic C in the soil. Soil erosion is controlled by cover crops, and eventually, loss of C from the soil is controlled (Blanco-Canqui et al., 2015). The roots of cover crops are fed by soil organisms, increasing the level of organic C in soil over time (Clark, 2015). In a study conducted by (Chahal et al., 2020), it was found that C of the plant was converted to soil organic carbon by 10-20 mg C ha^{-1} with cover crops than without cover crops. Using the data from 37 studies worldwide, it was estimated that cover crops could sequester about 0.32 ± 0.08 Mg ha^{-1} yr^{-1} of carbon to the 22 cm soil depth (Poeplau & Don, 2015). Perennial ryegrass (Lolium perenne L.) has vast potential for Soil Organic Carbon sequestration and thus has a high potential to be used as a cover crop species with high biomass production (Kuo et al., 1997). An experiment in the form of three Swedish long-term experiments (16-24) years was carried out by Poeplau et al. (2015) to examine the effect of perennial ryegrass as a cover crop on SOC stocks, and it was compared with a Sultan, a North American site. Mean Humification coefficients obtained from the experiment were 0.33 ± 0.27 for ryegrass, which was done to measure SOC efficiency and obtained using the introductory carbon balance model. The study found that perennial ryegrass can be used as an effective measure to increase SOC stocks even though the cover crop did not significantly affect the yield of the main crop.

2.2.2 Reducing soil Erosion

Cover crops can reduce up to 80% run-off loss and 40-96% sediment loss (Kaspar et al., 2001). Consequently, the dissolved nutrients from cover crops are not reduced as well, which improves water quality, soil fertility, and crop productivity (Kaspar et al., 2001). This suggests that pollution in water resources such as lakes, streams, ponds, etc., is also reduced. In an experiment, cover crops reduced the loss of dissolved nutrients by 77% (Zhu et al., 1989). In another experiment, it was recorded that total P in the run-off was 74% lower in plots treated with cover crops than the plots with no cover crops (Kleinman et al., 2005). A study done by Williams & Weil (2004) using a minirhizotron camera to monitor the root growth of cover crops has shown that cover crops could mitigate soil compaction effects.

Cover crops absorb energy from raindrops and increase roughness to the soil's surface, delaying run-off by decreasing run-off velocity, increasing water infiltration, and maintaining soil aggregation capacity (Blanco-Canqui et al., 2011). Cover crops are also responsible for reducing the risk of wind erosion (Blanco-Canqui, Holman, et al., 2013). Cover crops improve soil structure, increase organic C in soil, and anchor the soil well with their roots, thereby reducing wind erosion. High organic C in the soil increase the aggregating ability of soil-forming stable macroaggregates physically, chemically and biologically.

2.2.3 Soil moisture conservation

Cover crops increase the wet aggregate stability of the soil. Wet aggregates of soil are comparatively larger and more stable with cover crops than without cover crops (Blanco-Canqui et al., 2015). Stable aggregates of soil enhance the soil macroporosity and storage of water, C and nutrients (Blanco-Canqui, Shapiro, et al., 2013).

The residues from cover crops improve permanent organic binding agents to promote the aggregation capacity of the soil (Tisdall & Oades, 1982). Cover crops improve hydraulic properties of soil, i.e. water retention capacity, water infiltration capacity and saturated hydraulic conductivity. Increment in water infiltration in the range of 1.1 to 2.7 times was recorded in a study conducted by (Blanco-Canqui et al., 2015). They also maintain proper drainage in the soil profile (Kahimba et al., 2008).

2.2.4 Nitrogen assimilation

Cover crops trap N from the soil during the fallow season, reducing the loss of N from the soil by leaching or denitrification, and when they die, N is recycled back to the soil. The recycled nitrogen improves the soil's organic matter. The nitrogen that would otherwise have been lost from the cropping system could be preserved through the selection of suitable cover crop species (Thomsen, 2005). The time of cover crops sowing and its incorporation affect the amount of nitrogen leaching from the soil. Karlsson-Strese et al., (1998) stated that delaying autumn incorporation decreases the N leaching risk from the agricultural systems.

In a study conducted by (Kaspar & Singer, 2011), it was found that cover crops reduced the potential of NO_3 leaching losses in the range of 6-94%. Cover crops have the capacity to fix atmospheric Nitrogen (Blanco-Canqui et al., 2015). Incorporating residues of cover crops promotes N mineralisation. They provide a large amount of N in the soil to be used by the subsequent main crops (Daryanto et al., 2018). During the winter, due to the percolation of water in the soil, leaching of nitrogen can occur (Turtola & Kemppainen, 1998), and in the spring, when the soil thaws and snow melts, a large amount of soil water may drain in. In both cases, before the new growing season begins, mineralisation and movement of N from the topsoil to deeper soil horizons occur. In such cases, sowing of an appropriate cover crop can prevent the leaching of nitrogen.

In the regions with intensive agriculture and high precipitation, undersown non-legume cover crops like Italian ryegrass or perennial ryegrass are highly efficient in reducing nitrogen leaching from those regions (Aronsson & Torstensson, 1998). In Norway, cover crops planted during autumn and winter provide protective plant cover and are effectively used to mitigate soil and phosphorous erosion along with the reduction in nitrogen leaching (Aronsson et al., 2016). In the Nordic countries, during spring cereal production, non-legume catch crops represent a universal and effective method for reducing N leaching across the varieties of soils and weather(Valkama et al., 2015). According to Garwood et al., (1999), when a catch crop is incorporated in spring, it is most effective in reducing nitrate leaching. However, the yield may be compromised if catch crops are allowed to grow during winter.

2.2.5 Enhance of biological properties of soil

Cover crops have a positive impact on the microbial community of soil. Increased infiltration capacity and soil aggregate stability enhance the population of earthworms. An increased number of heterotrophic bacteria, high microbial biomass C and increased soil enzymatic activities were found in the study (Kirchner et al., 1993). The increase in microbial activity under cover crops is positively correlated with an increase in soil organic C (Mullen et al., 1998).

Arbuscular mycorrhizal fungi could be increased by cover crops that interact with the living roots of cover crops(Lehman et al., 2014). Cover crops provide habitat to the beneficial insects, having a positive impact on their population (Goławski et al., 2013). They also enhance wildlife habitat and diversity. Cover crops are found to suppress the weed population (Mirsky et al., 2011), and this ability is thought to be due to various reasons like cover crop competition with weeds for light, water and nutrient and inhibition of weed seed germination due to shading (Hiltbrunner et al., 2005). In an experiment by (Gerhards, 2018), it was found that the plot with perennial ryegrass and white clover that was sown as a cover crop in the cereal crop plot had significantly reduced the weed density to 22 plants $m^2$and 25 plants m^2 compared to the control plot which had weed density 45 weed plants m^2.

2.3 Yield and Economic Importance of Cover Crops

The economic importance of biotic control using cover crops in reducing the nitrate leaching and protecting soil resources in the agricultural food production system was mentioned by Oluwajobi,(2016). After the main crop is harvested, the short duration crops as cover crops can be sown in the autumn to maintain soil fertility. The use of short duration cover crops can be cost-effective compared to green manures because cover crops can be grown more frequently, whereas the green manures are grown during the whole season (Thorup-Kristensen et al., 2011). A study conducted by Miguez & Bollero,(2005) used meta-analysis to quantify the effects of winter cover crops on corn yield. Results suggest that bicultural and grass cover crops had an overall positive effect on corn yields. Bicultural cover crops increased corn yields by 21%. Legume cover crops increased corn yields by37% when no nitrogen was applied. However, the grasses did not affect corn yields. Likewise, in an experiment by Deleuran & Boelt, (2009), the placement of the ryegrass seed crop 6 cm from the cereal row showed that a significant yield increase of 34–71 kg ha−1 could be obtained compared with sowing in the cereal row.

3 MATERIALS AND METHODS

The materials used and the methods adopted for the study have been described in this section under the following headings.

3.1 Description of the experimental site

The experiment was conducted in the research plot of Innlandet University College, Blæstad, Ridabu, from May to September 2019 and April to August 2020. The experimental site is situated at Innlandet, Norway, 7 km east of Hamar, approximately127 masl. Geographically, the experiment site was located at 60˚82’ North and 11 ˚18’ East.

3.1.1 Physico-Chemical properties of experimental soil

Soil samples were taken from the field in 2020 and sent for analysis at Eurofins (Moss, Norway). The soil was of the moraine soil type, where the soil type was classified as loamy clay with 4.3%

organic matter content (class 2). Plant-available phosphorus (P-AL) number was 9 (class C1), plant-available potassium (K-AL) was 5 (class 1), and pH was 7.8, which is due to the fact that there is limestone under the moraine soil here quite a reason as shown in **appendix 1**.

3.1.2 Climatic condition during experimentation

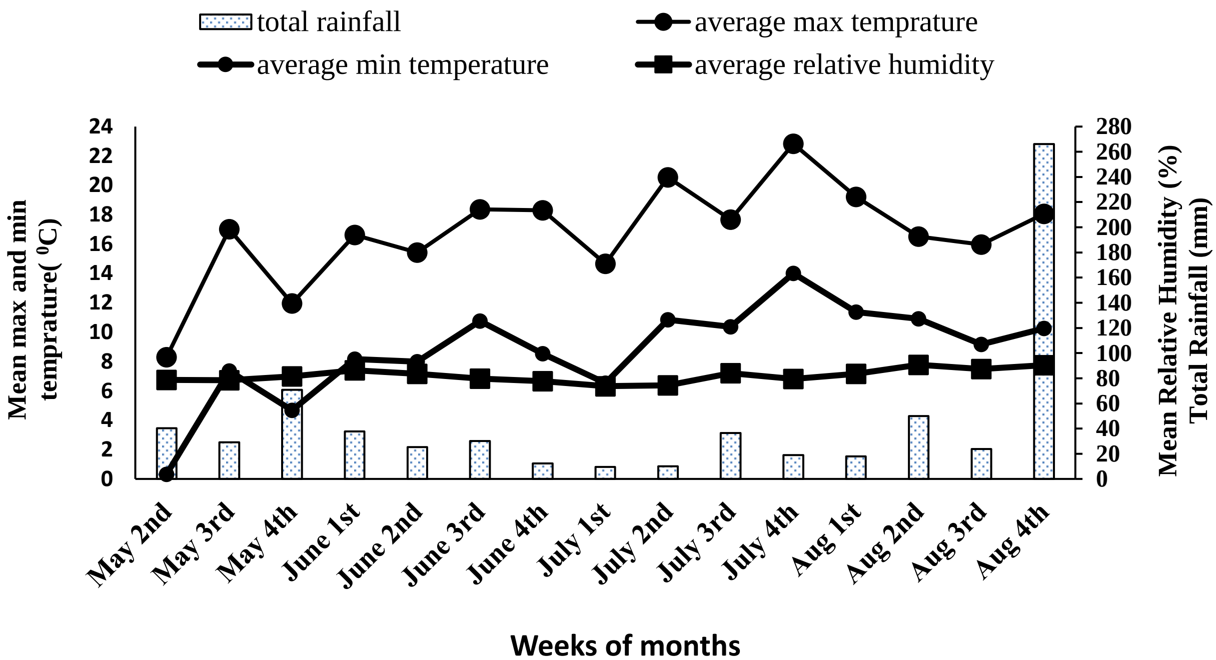

Figure1: Weekly mean maximum and minimum temperature (^{0}C), Relative humidity (%) and total rainfall (mm/day) for the experimental period during 2019.

In 2019, Highest maximum temperature (28.25 °C) was recorded in the fourth week of July and the lowest maximum temperature was recorded in the second week of May, i.e. 4.55 °C. The highest average maximum temperature was obtained in the first week of July (22.83 °C). The lowest average maximum temperature was obtained in the first week of May, i.e. 8.3 °C (Appendix 2). The lowest minimum temperature was recorded on May 8, i.e. -2.27 °C and the highest minimum temperature (17.62 °C) was recorded in the fourth week of July. The lowest average minimum temperature was obtained in the first week of May, i.e. 0.32 °C and the highest average minimum temperature was obtained in the first week of July, i.e. 14 °C. The coldest month was May and the hottest month was July. The highest precipitation was obtained on July 21, i.e. 22.88 mm (Appendix 2). Relative humidity was recorded as the highest on May 9, i.e. 97.12%, and it was the lowest on May 13, i.e. 60.81%. The average relative humidity was highest on August 2, i.e. 90.72% and lowest on July 1, i.e. 73.75%. The cumulative rainfall during the cropping period was 266mm, as shown in appendix 2.

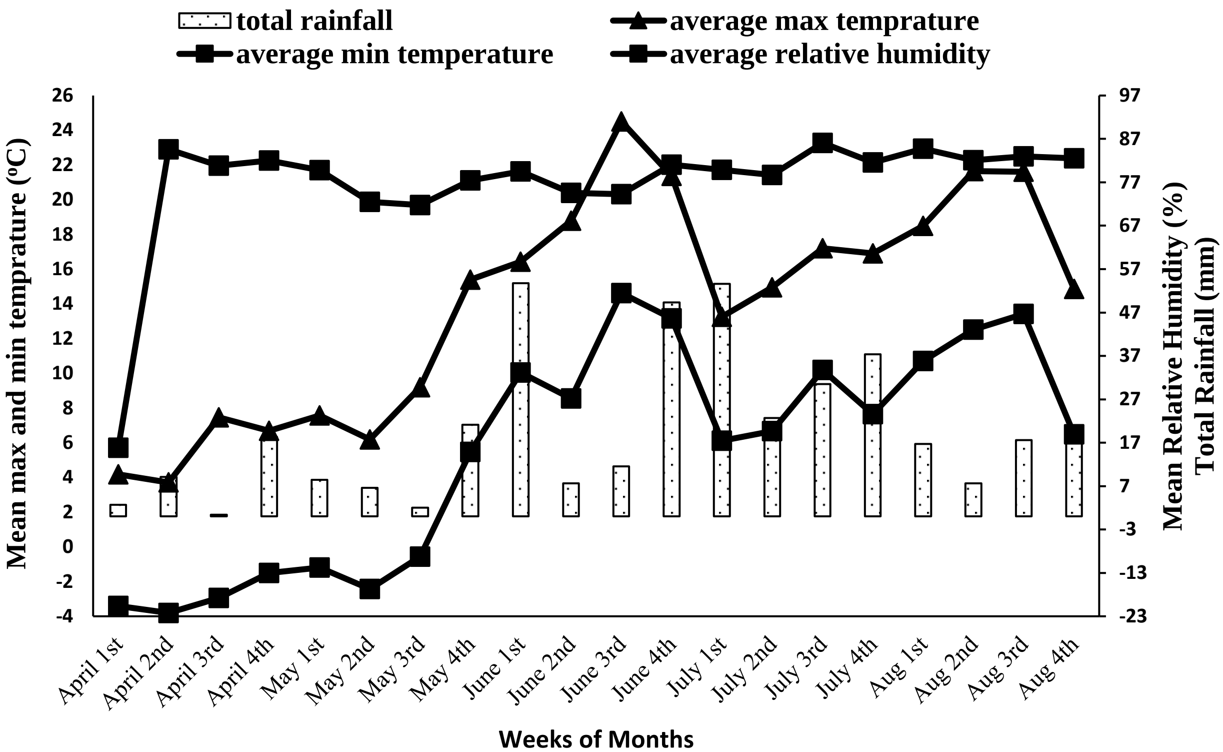

Figure1: Weekly mean maximum and minimum temperature (^{0}C), Relative humidity (%) and total rainfall (mm/day) for the experimental period during 2020.

In 2020, maximum precipitation was received in the first week of June, i.e. 53.76mm, and the lowest was received in the third week of April, i.e. 0.37mm. The average relative humidity was the lowest in the first week of April, i.e. 15.84% and highest in the fourth week of July, i.e. 86.08%, as shown in appendix 3. The highest average maximum temperature was obtained in the third week of June, i.e. 24.51°C and the lowest was obtained in the second week of April, i.e. 3.71 °C. The highest average minimum temperature was obtained in the third week of June, i.e. 14.62°C and the lowest was obtained in the second week of April, i.e. 3.81°C, as shown in appendix 3.

3.2 Experimental details and Experimental design

3.2.1 Experimental design

The experiment was laid out in a split-plot design with seven treatments on two crops and three replications for each treatment. The experiment was done in 2019 and 2020. The experiment was conducted with wheat and barley as main plot treatments, whereas the cover crop and their different sowing time were sub-plot treatments. Each treatment was allocated in an individual experimental plot of size 22.5 m^2 (9 m× 2.5 m). The total experimental area was 945 m^2.

3.2.2 Treatment details

The experiment had two main factors

A. **Main Plot Factor**: Cereal Crops

1. Barley
2. Wheat

B. **Sub-Plot Treatments**: Cover crops and sowing time

T_1: Italian Rye Grass sown on the same day

T_2: Italian Rye Grass sown two weeks later

T_3: Perennial Rye Grass sown on the same day

T_4: Perennial Rye Grass sown two weeks later

T_5: Meadow Fescue sown on the same day

T_6: Meadow Fescue sown two weeks later

T_7: Control

3.2.3 Treatment Application

The same species and the amount of cover crop was included in the experiments over the two years. In 2019, the experiments were carried out in spring-sown barley (Hordeum vulgare L.) variety 'Salome' from Strand Unikorn (batch 8168402), 210 kg ha^{-1}, and in spring wheat (Triticum aestivum L.) variety 'Miracle' from Strand Unikorn (lot 8328905, 220 kg ha^{-1}. The grain was sown on large squares (main plot block) on 8 May with Wäderstad Rapid, while the cover crops were sown on small plots (9 × 2.5 m) with a Nordsten seed drill, three repetitions of each trial stage in each grain species. The experimental field in 2019 also had catch crops two weeks after sowing the grain.

In 2020, the fields were laid out in the spring wheat ‘Miracle’ (220 kg/ha) and in the spring-sown barley ‘Rødhette’ (180 kg/ha). The field was laid out on 4 April, and here the field was sown with an experimental seed drill in collaboration with NLR Innlandet. The Italian Ryegrass, the perennial Ryegrass and the meadow Fescue were the used cover crops. These crops were sown on two dates, i.e., on the same day with major cereals or two weeks after sowing. Along with this, a control plot in which no cover crops were sown was used as a control to make a check of sole crops of cereals against the cover cropping. This makes seven different treatments for both barley and wheat crops. The cover crop was sown at approximately 1 cm deep. The seed lobes were adjusted so that the catch growth was sown between the rows of grain.

In both years, the same species of catch crops were included in the experiments (as shown in section 3.2.2). The experimental fields were treated the same way as the rest of the field. It was fertilised with approx. 56 kg/day of the type 20-4-11 (YaraMila complete fertiliser). This corresponds to approx. 110 kg nitrogen / ha. In addition, weed was sprayed with Ariane-S during the season.

3.2.4 Crop harvest

The crops were harvested after seeing the maturity indices of each crop, and the cover crop was also harvested. The threshed grains were sun-dried and were stored at 15% moisture. For the estimation of above-ground dry matter of each cover crop, the crop was oven-dried to avoid all moisture content, and dry matter production was analysed by weighing the crop.

The application of treatment and the layout of the field is as illustrated in the figure below:

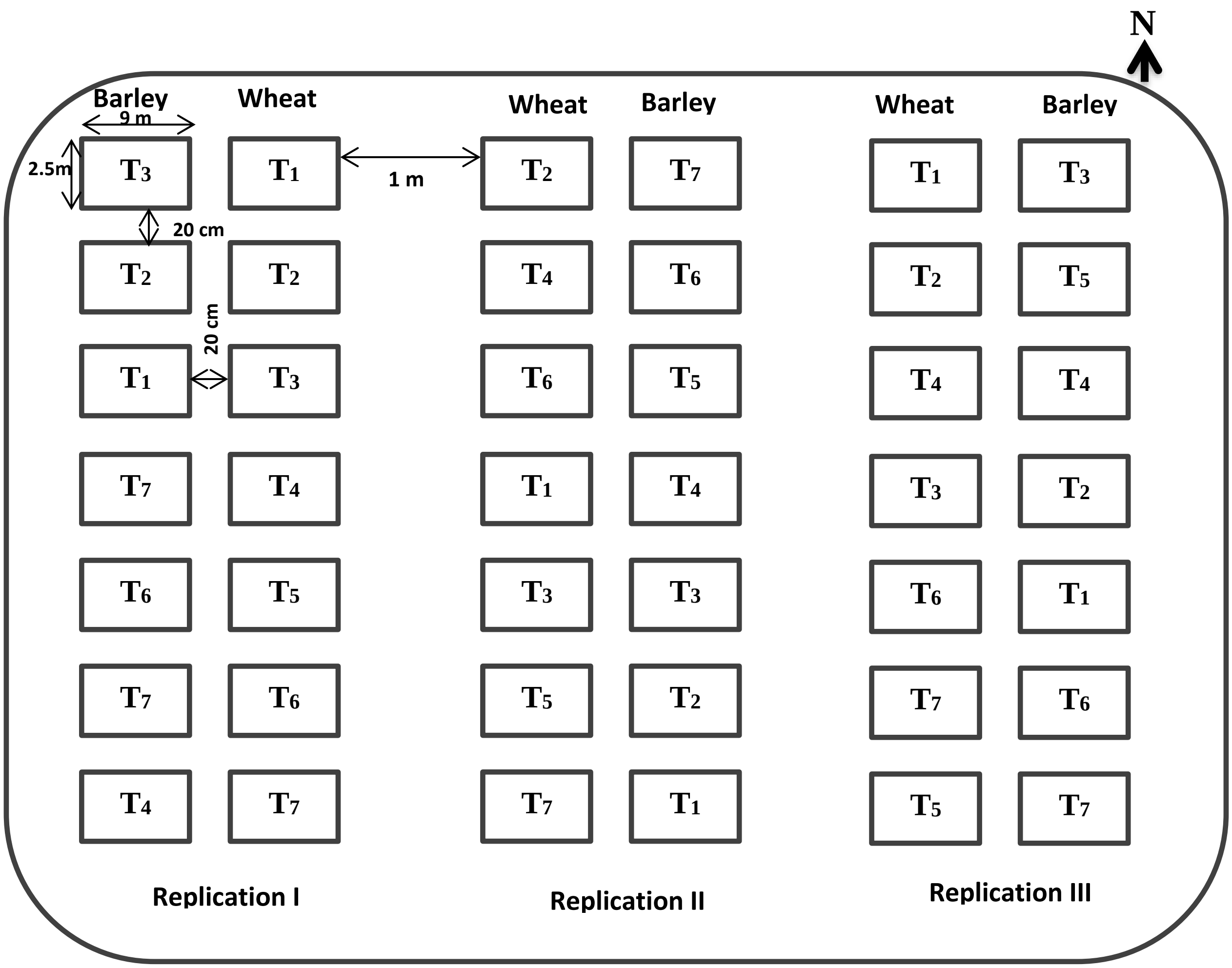

Figure 3: Layout of the field at the experimental site, Innlandet University College, Blæstad, Ridabu, during May, 2019 and April, 2020

Note: T_1, Italian Rye Grass sown on the same day; T_2, Italian Rye Grass sown two weeks later; T_3, Perennial Rye Grass sown on the same day; T_4, Perennial Rye Grass sown two weeks later; T_5: Meadow Fescue sown on the same day; T_6, Meadow Fescue sown two weeks later; T_7, Control.

3.3 Observation recorded for different crops

The various data were recorded from the field and the techniques adopted for each measurement are explained as follows:

3.3.1 Cover crop height

The height of the cover crop was taken on the day of cereal crop harvest and four weeks after the harvest of cereal crops. For this measurement, five plants were measured from the ground surface to the top of the plant, and the data were averaged to obtain the average height of crops under each experimental plot.

3.3.2 Cover crop growth

For the assessment of the growth of the cover crop, a net plot area at the centre of the plot was selected on each experimental plot. The area covered by the cover crop was assessed through visual observation and was scaled from 1to 9, where the least coverage was provided with a scale of 1, whereas the most vigorously growing cover crop was scaled as 9. The data was recorded at the time of grain harvest and four weeks after the harvest of wheat and barley.

3.3.3 Above ground dry matter production of cover crops

A small quadrate of 0.5m×0.5m was made within each experimental unit representing the average condition to harvest the cover crop. The cover crop was uprooted from the quadrant, the root was removed, and the above-ground part was oven-dried, weighed, and converted to kg ha^{-1}.

3.3.4 Weed percentage

The infestation of weeds was recorded from the field at the time of harvest of wheat and barley. The area covered by the weed was visually observed and was expressed in terms of percentage coverage of weed.

3.3.5 Grain yield

The wheat and barley crops were harvested from the experimental plots and then were dried. The grains were dried and the moisture percentage was determined for each experimental unit. The yield was then computed at 15% moisture in kg ha^{-1} using the following formula:

Grain yield (kg ha^{-1}) at 15% moisture = $\frac{(100-\text{MC}) \times \text{plot yield (kg)} \times 10000\ \text{m}^2}{(100-15) \times \text{net plot area}}$

Where, MC is the moisture content in percentage of the grains.

4 RESULTS

The results obtained from the experiment are analysed and presented in this chapter with the help of tables wherever necessary.

4.1 Grain yield of wheat and barley in 2019

The average grain yield (kg/daa) of barley and wheat was 635.64 and 567.90, respectively as shown in table 1. However, their yield was found to be statistically non-significant. The grain yield (kg/daa) of cereal crops was highest (670.50 kg/daa) and lowest for Italian ryegrass sown on the same day but was found to be statistically non-significant at sowing on the same day as well as two weeks later.

Table 1: Grain yield (kg/daa) as influenced by the main crops and cover crop and sowing time in Norway, 2019.

Treatment	Yield (kg/daa)
Main crops	
Barley	635.64
Wheat	567.90
SEm (±)	33.87
LSD (=0.05)	72.96 (ns)
CV, %	9.10
Cover crop and sowing time	
Italian Rye Grass same day	570.75
Italian Rye Grass two weeks later	572.57
Perennial Rye Grass same day	632.23
Perennial Rye Grass two weeks later	670.50
Meadow Fescue same day	594.38
Meadow Fescue two weeks later	584.82
Control	587.13
SEm (±)	13.82
LSD (=0.05)	102.74 (ns)
CV, %	12.30
Grand Mean	601.77

Note: Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test.

4.2 Cover crop plant height (cm)

Plant height of the cover crop (cm) was found statistically non-significant at grain harvest as well as at four weeks after the grain harvest as influenced by main crops. Similarly, the plant height of cover crop (cm) was found to be statistically non-significant at grain harvest as influenced by co ver crops and sowing time.

Table 2: cover crop plant height (cm) as influenced by the main crops and cover crop and sowing time in Norway, 2020.

Treatment	Cover crop height (cm)	
	At grain harvest	Four weeks after grain harvest
Main crops		
Barley	11.5	18.89
wheat	11.0	14.89
SEm (±)	0.25	2.00
LSD (=0.05)	2.14 (ns)	5.68(ns)
CV, %	13.33	23.5
Cover crop and sowing time		
Italian Rye Grass same day	12.67	24.17[a]
Italian Rye Grass two weeks later	11.00	14.83[bc]
Perennial Rye Grass same day	11.17	17.67[b]
Perennial Rye Grass two weeks later	11.00	14.83[bc]
Meadow Fescue same day	10.67	16.33[bc]
Meadow Fescue two weeks later	11.00	13.50[c]
SEm (±)	0.29	1.57
LSD (=0.05)	9.40 (ns)	2.79***
CV, %	15.5	13.7
Grand Mean	11.25	16.89

Note: Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. * significant at 5%; ** significant at 1%; *** significant at 0.1%;

Plant height of cover crop (cm), four weeks after grain harvest, was significantly influenced by cover crop and sowing time. The greatest plant height was recorded from Italian Ryegrass sown on the same day (24.17 cm) which was significantly higher than other treatments. This was followed by Perennial Rye Grass sown on the same day (17.67 cm) which was statistically at par with theMeadow Fescue sown on the same day (16.33), Italian Rye Grass sown two weeks later (14.83 cm), and Perennial Rye Grass sown two weeks later (14.83 cm). The smallest plant height was recorded from Meadow fescue sown two weeks later (13.5 cm), as shown in table 2.

4.3 Growth of cover crops

The growth of cover crop growth was found to be significantly influenced by main crops at grain harvest but was found to be non-significant four weeks after grain harvest. At grain harvest, the highest crop growth was scaled 4 for wheat, and the lowest cover crop growth was scaled 3.0 6 for barley.

The growth of cover crop growth at grain harvest and at four weeks after grain harvest was found to be significantly influenced by cover crop and sowing time. At grain harvest, the highest cover crop growth was recorded from Italian Rye Grass sown on the same day (7), which was statistically at par with Italian Rye Grass sown two weeks later 3.67), Perennial Rye Grass sown on the same day (3.33), Meadow Fescue sown at the same day (3), and Perennial Rye Grass sown two weeks later (2.66). The lowest cover crop growth was recorded from Meadow Fescue sown two weeks later (1.5), as shown in table 3.

After four weeks of the grain harvest, the highest cover crop growth was recorded from Italian Rye Grass sown on the same day (7.33). It was followed by Perennial Rye Grass sown on the same day (3.67) which was statistically at par with Italian Rye Grass sown two weeks later (3.33), and Perennial Rye Grass sown two weeks later (2.67), and Meadow Fescue sown at the same day (2.67). The lowest cover crop growth was recorded from Meadow Fescue sown two weeks later (2.33) as shown in table 3.

Table 3: Cover crop growth (scale 1-9) on the day of harvest and a month after the harvest of main crops influenced by the main crops and cover crop and sowing time in Norway, 2020.

Treatment	Cover crop Growth (scale 1-9)	
	At grain harvest	Four weeks after grain harvest
Main crops		
Barley	3.06^{b}	3.67
Wheat	4.00^{a}	3.67
SEm (±)	0.47	0
LSD (=0.05)	0.86*	0.01
CV, %	17	0
Cover crop and sowing time		
Italian Rye Grass same day	7.00^{a}	7.33^{a}
Italian Rye Grass two weeks later	3.67^{ab}	3.33^{bc}
Perennial Rye Grass same day	3.33^{ab}	3.67^{b}
Perennial Rye Grass two weeks later	2.66^{ab}	2.67^{bc}
Meadow Fescue same day	3.00^{ab}	2.67^{bc}
Meadow Fescue two weeks later	1.5^{b}	2.33^{c}
SEm (±)	0.76	0.76
LSD (=0.05)	3.95***	0.98***
CV, %	29.4	22.30
Grand Mean	3.53	3.67

Note: Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. * significant at 5%; ** significant at 1%; *** significant at 0.1%;

4.4 Above ground biomass yield of cover crop

Above-ground biomass yield of the cover crop (kg/ha) was significantly influenced by the main crops, where the highest biomass was obtained from wheat (569.21 kg/ha), and the lowest was obtained from barley (301.44 kg/ha) table 4.

Similarly, the above-ground biomass yield of cover crop (kg/ha) was also significantly influenced by cover crop and sowing time. The highest biomass was obtained from Italian Rye Grass sown on the same day (991.07 kg/ha). It was followed by Italian Rye Grass sown two weeks later (460.64 kg/ha), which was statistically at par with Perennial Rye Grass sown on the same day (336.07 kg/ha), Perennial Rye Grass sown two weeks later (321.56 kg/ha) and Meadow Fescue sown at the same day (299.62 kg/ha). The lowest above-ground biomass of cover crop was recorded from Meadow Fescue sown two weeks later (202.99 kg/ha) table 4.

Table 4: Above ground biomass yield of cover crop (kg/ha) as influenced by the main crops and cover crop and sowing time in Norway, 2020.

Treatment	Above-ground biomass yield of cover crop (kg/ha)
Main crops	
Barley	301.44[b]
wheat	569.21[a]
SEm (±)	133.88
LSD (=0.05)	52.63**
CV, %	11.10
Cover crop and sowing time	
Italian Rye Grass same day	991.07[a]
Italian Rye Grass two weeks later	460.64[b]
Perennial Rye Grass same day	336.07[bc]
Perennial Rye Grass two weeks later	321.56[bc]
Meadow Fescue same day	299.62[bc]
Meadow Fescue two weeks later	202.99[c]
SEm (±)	116.14
LSD (=0.05)	209.51***
CV, %	40.00
Grand Mean	435.33

Note: Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. * significant at 5%; ** significant at 1%; *** significant at 0.1%;

4.5 Grain Yield and weed infestation

Grain yield (kg/ha), at 15% moisture was found to be significantly influenced by main crops. The highest grain yield was recorded from barley (4355.08 kg/ha), and the lowest grain yield was recorded from wheat (3121.63 kg/ha). While, grain yield (kg/ha), at 15% moisture was found to be statistically non-significant as influenced by both cover crop and sowing time, as shown in table 5.

The percentage of weeds as influenced by main crops was also found to be statistically non-significant. However, weed percentage was significantly influenced by cover crop and sowing time. The highest weed percentage was obtained with control (4.19 %). It was followed by Meadow Fescue sown on the same day (2.85 %), which was statistically similar to Meadow Fescue sown two weeks later (2.82 %), and Perennial Rye Grass sown two weeks later (2.56 %). The smallest result was obtained from Italian Rye Grass sown on the same day (0.71 %), as shown in table 5.

Table 5: Grain yield 15% moisture (kg/ha)) and weed percentage as influenced by the main crops and cover crop and sowing time in Norway, 2020.

Treatment	Grain yield	Weed percentage
Main crops		
Barley	4355.08[a]	2.95
wheat	3121.63[b]	1.88
SEm (±)	616.73	0.54
LSD (=0.05)	1190.61*	2.04 (ns)
CV, %	24	63.70
Cover crop and sowing time		
Italian Rye Grass same day	3541.68	0.71[d]
Italian Rye Grass two weeks later	3736.65	1.90[c]
Perennial Rye Grass same day	3816.53	1.88[c]
Perennial Rye Grass two weeks later	3696.13	2.56[b]
Meadow Fescue same day	3770.38	2.85[b]
Meadow Fescue two weeks later	3819.19	2.82[b]
Control	3787.92	4.19[a]
SEm (±)	36.71	0.41
LSD (=0.05)	232.21(ns)	0.61
CV, %	5.2	21.2***
Grand Mean	3738.35	2.42

Note: Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. Same letter(s) within column represent non-significant difference at 0.05 level of significance based on Duncan multiple range test. * significant at 5%; *** significant at 0.1%;

The effect of the interaction of main crops with cover crops and sowing time for weed percentage was found to be statistically significant. The highest result was recorded from the interaction of control and barley (4.98). The lowest result was recorded from the interaction effect of Italian Rye Grass sown on the same day and wheat (0.71), which was statistically similar to the interaction effect of Italian Rye Grass sown two weeks later and wheat (0.71), as shown in table 6.

Table 6: Weed percentage as influenced by the interaction of main crops and cover crops and sowing time in Norway, 2020.

Treatment	Weed percentage	
	Barley	Wheat
Italian Rye Grass same day	0.00 (0.71)^{e}	0.00 (0.71)^{e}
Italian Rye Grass two weeks later	10.00 (3.09)^{b}	0.00 (0.71)^{e}
Perennial Rye Grass same day	6.67 (2.54)^{bc}	1.67 (1.22)^{de}
Perennial Rye Grass two weeks later	10.00 (3.090^{b}	5.00 (2.04)^{cd}
Meadow Fescue same day	10.00 (3.16)^{b}	6.67 (2.54)^{bc}
Meadow Fescue two weeks later	10.00 (3.09)^{b}	6.67 (2.54)^{bc}
Control	25.00 (4.98)^{a}	11.67 (3.40)^{b}
LSD	0.68*	

Note: The figures in parenthesis represent the square root transformation of the original figures during analysis.

5 DISCUSSION

The results obtained are discussed with possible reasons under the following headings with supporting literature.

5.1 Effect of cover crop on weed management dry matter production

The results showed fewer weeds with the use of cover crops, and this was obtained in both barley and wheat. The weed was maximum (4.90%) and was significantly higher than the plots with cover crops because of the weed-suppressing ability (Table 5). Weed suppression ability of the cover crops is assumed because of their ability to compete with the weed for light, water, nutrition and inhibit the germination of weed seed because of the shading (Hiltbrunner et al., 2005). Hartl (1989) stated that the dry biomass of living mulch and weed suppressive ability are often positively correlated. Perennial ryegrass, less competitive usually survives the winter, so it is clearly dominating cover crop species in terms of use of cover crops in agriculture field trials (Känkänen & Eriksson, 2007b). Less competitive ability of Perennial Rye Grass than Italian Rye Grass was also stated by (Weston, 1990) as in the experiment it was found that Italian Rye Grass was found to be significantly superior in the establishment of row crops than Perennial Rye Grass. In the current experiment, the above-ground dry matter yield was maximum for Italian ryegrass, and hence the weed suppression was also maximum (0.71%) for that cover crop (table 5). Likewise, in an experiment with soybean, Italian Rye Grass was found to reduce annual weed by 53%. Cover crops can block sunlight to the weed seeds and prevent them from germinating (Creech, 2018). The residues from cover crops intercept and reflect the short wave radiation which reduce the quantity of light required to activate phytochrome- mediated germination, also reduce soil absorption from the soil (Teasdale, 1996). In a study studied by (Weston, 1990), it was found that Perennial Rye Grass strongly suppressed the growth of weeds. In an experiment, the biomass of weeds was significantly lower in all cover cropping systems than in the control treatment (Yenish et al., 2017). Also, in irrigated and non-irrigated trials in Kentucky conducted by (Yenish et al., 2017), the high rate and frequent seeding of Perennial Rye Grass competed with perennial weeds and contributed to reduced weed biomass.

In the experiments at Blæstad, Innlandet, the average dry weight yields of the cover crops were low and in the range of 200-900 kg/ha. The current experiment had the above-ground dry matter of Italian rye Grass to be maximum dry matter yielding (991.07 kg ha^{-1}) when sown on the same day as the main crop (table 4). This was in accordance with the finding of (Cornelius & Bradley, 2017), where the yield of Italian Rye Grass was 1179 kg/ha and with a plant height of 15-20 cm in the first year.

The current experiment highlighted the tremendous dry matter production from the cultivation of cover crops than the plots with no cover crops. Perennial ryegrass (*Lolium perenne* L.) has enormous potential for Soil Organic Carbon sequestration. It thus has a high potential to be used as a cover crop species with high biomass production (Kuo et al., 1997). The study found that perennial ryegrass can be used as an effective measure to increase SOC stocks even though the cover crop did not significantly affect the yield of the main crop as examined by Poeplau et al.,(2015).

5.2 Effect of sowing date on the growth of cover crop

The experiment at Innlandet showed that the grand mean value of cover crop plant height increased from grain harvest date to four weeks after grain harvest. The mean plant heights were 11.25 cm and 16.89 cm at grain harvest and four weeks after grain harvest, respectively (Table 2). The mean cover crop growth increased from the grain harvest date to 4 weeks after grain harvest. It was a maximum (3.67) at four weeks after grain harvest (Table 3). Seeding dates can influence the biomass production of cover crops (Stahl, 2020). September is considered to be suitable for sowing cover crops so that they will remain and mature all over the winter (Carroll, 2 021)

Cover crop planting is suitable during the long interval between summer harvest and the sowing of spring crops. Such long intervals are usually occurring in temperate European regions. However, seeding of a cover crop can be suitable between the time period of the summer harvest and the sowing of the winter crops (Büchi et al., 2018). (Blaser et al., 2007). Perennial cover crops are incorporated before the winter seasons in the northern temperate areas to reduce the negative effect of low soil mineral nitrogen content occurring as a result of the sowing of main crops in the spring season (Tonitto et al., 2006). (Moore et al., 2019). In the late autumn, Italian ryegrass was the most competitive species with spring barley (Känkänen & Eriksson, 2007c). (Hashem et al., 1998) studied competitive ability of Italian Rye Grass increased whereas the competitive ability of the main crop decreased with time.

5.3 Competition of cover crops with the main crop

The research at Innlandet conducted in 2020 showed that the yield of cereal crops was reduced by 6.33% by perennial ryegrass sown at the same time, but only 1.3% of yield was reduced by the same grass when sown two weeks later. The perennial ryegrass sown after two weeks of sowing main crops reduced the yield by 2.4%, whereas the yield of cereals was increased by 0.7% by perennial ryegrass sown on the same day. Hence there has not been a significant impact on the yield, or no significant reduction of yield was experienced (Table 5), and a similar result was also obtained in 2019. A similar result was also obtained by (Poeplau et al.,2015). An experiment by, Valkama et al., (2015) showed that the yield reduction due to perennial ryegrass under sown at the same time or shortly after the main crop, with seed rate of 7 to 10 kg ha^{-1} (6.2 to 8.9 lb ac^{-1}) was usually less than 3% while for Italian or annual ryegrass it was between 5% and 20%. The Production of wheat decreased up to 60% as the densities of Italian ryegrass increased (Appleby et al., 1976). Wheat biomass was found to be greater when grown with Italian ryegrass than grown in monoculture. The competition effect of Italian ryegrass on winter wheat increased over time, reaching a maximum at 225 days after emergence. The total variation in plant size of Italian ryegrass accounted for 40-60% of wheat density and 4-34% of Italian ryegrass density. Plant size of Italian ryegrass was less influenced by winter wheat after 170 Days after emergence, while the influence of ryegrass increased with the age of plants. This result shows that wheat in mixtures experienced increased interspecific competition after 170 Days after emergence, whereas Italian ryegrass experienced increased intraspecific competition. The plant height of Italian ryegrass was recorded to be 40-80 cm at the reproductive stage (Hashem et al., 1998). The non-significant reduction in yield might be due to the reduction in weed infestation by the cover crop. Weeds are the major reason for decreasing the yield, and since the cover crops effectively control weeds, the yield was not significantly reduced.

A similar result was found in an experiment by Gerhards,(2018) in Southwestern Germany near Stuttgart at the Research Station of the University of Hohenheim. It was found that weed density was reduced up to 97% in spring barley by early and late sowing with the perennial ryegrass. The reduction was assumed probably due to moist and warm weather during the spring season. Ohlander et al., (1996) studied the possibility of reducing competition of undersown catch crops on spring barley.

The experiment conducted stated no significant statistical differences were recorded on spring barley due to the influence of undersown cover crops (Känkänen & Eriksson, 2007a), while above-ground biomass yield was found to be the highest in Italian Rye Grass, and the lowest was obtained from Meadow Fescue at the harvest of barley. Italian Rye Grass grew the best. Meadow Fescue grew poorly at the harvest. Italian Rye Grass yielded the highest N. The experiment by (Charles, 1970) showed that 1000 grain weight of barley was reduced more by Italian Rye Grass used as cover crop compared to others while (Creamer & Bennett, 1997) stated that perennial ryegrass did not compete well as compared to Italian Rye Grass with main crops. Poeplau et al.,(2015) reported that cover crop did not significantly affect the yield of the main crop.

5.5 Reasons for non-preference of the cover crop by farmers

The conducted study showed several benefits of using cover crops.

The choice of cover crop to be grown in a field largely depends upon the objective, such as to control soil erosion, for pest suppression or for enhancing soil fertility, while farmers strictly pay attention to the type of cover crops to be integrated into their farm (Snapp et al., 2005). Mallory et al., (1998) have mentioned the lower adoption of cover crops despite substantial ecological advantages, while Nowak,(1992) has stated that the less adoption of new technology, which also includes cover crops integration in the farms, might be due to either unwillingness of the farmers due to their ignorance or either they are unable to adopt because of low profitability arising with the cover crop cultivation. The sown cover crops might become vigorous and affect the growth and yield of the main crop, or sometimes their incorporation in the field might become troublesome to the farmer because of the lack of equipment necessary for their incorporation, as found by Stivers-Young, (1998) in a conventional cover cropping system where winter rye was used as a cover crop after potato or other cash crops. With the cover cropping, there are some problems encountered. The addition of establishment cost affects the establishment of succeeding crops due to slow soil warming or delayed organic nitrogen release and cover crop management problems like chances of cover crops acting as weeds, difficulty in killing vigorous cover crops etc. (Snapp et al., 2005) or sometimes reduction in crop yield as mentioned by Känkänen & Eriksson, (2007) as they found the reduction of grain yield of barley with intense early growth of undersown crops. Thus, the systems that reduce the cover cost establishment and strategies to overcome subsequent crop establishment problems should be developed to encourage the farmers to adopt cover cropping systems in their farms, as suggested by Dabney et al.,(2001).

Despite all these, some farmers have adopted growing cover crops with cereal crops. The major reasons include:

- It has a lot of good ecosystem services.
- Harvesting challenges, technology, complicated, foreign material, the introduction of new weeds,
- Low cost of seeds of cover crops
- Pests, and diseases, may be harmful to the main crop.

6 SUMMARY AND CONCLUSIONS

The experiment was conducted from May to September 2019 and April to August 2020 at the research plot of Innlandet University College, Blæstad, Ridabu, Norway, to identify the best cover crop and best sowing time for maximising the yield and getting ecological services from the cover crops. The experiment was executed in a split-plot design with wheat and barley as main plot treatments and the various cover crops and their seeding time, viz. Italian Rye Grass sown on the same day, Italian Rye Grass sown two weeks late, Perennial Rye Grass sown on the same day, Perennial Rye Grass sown two weeks later, Meadow Fescue sown on the same day, Meadow Fescue sown two weeks later as sub-plot treatments including control in which no cover crops were grown. The experiment was repeated thrice.

In 2019, the experiments were carried out in spring-sown barley (Hordeum vulgare L.) variety 'Salome' from Strand Unikorn (batch 8168402), 210 kg ha^{-1}, and in spring wheat (Triticum aestivum L.) variety 'Miracle' from Strand Unikorn (lot 8328905, 220 kg ha^{-1}. The grain was sown on large squares (main plot block) on 8 May with Wäderstad Rapid, while the cover crops were sown on small plots (9 × 2.5 m) with a Nordsten seed drill, three repetitions of each trial stage in each grain species kg/ha). The field was laid out on 4 April, and here the field was sown with an experimental seed drill in collaboration with NLR Innlandet. In 2020, the fields were laid out in the spring wheat 'Miracle' (220 kg/ha) and in the spring-sown barley 'Rødhette' (180 kg/ha). The experimental fields were treated the same way as the rest of the field. It was fertilised with approx. 56 kg/day of the type 20-4-11 (YaraMila complete fertiliser). This corresponds to approx. 110 kg nitrogen / ha. In addition, weed was sprayed with Ariane-S during the season.

There were no significant differences in grain yield influenced by main crops as well as by cover crops and their sowing time. Cover crop's plant height significantly differed as influenced by cover crop and their sowing time only four weeks after grain harvest. Italian Rye Grass sown on the same day recorded the greatest plant height, whereas Meadow Fescue sown two weeks later recorded the smallest plant height. The highest crop growth was obtained from wheat at grain harvest, and the lowest cover crop growth was obtained from barley. Cover crop growth was found to be highly significant at grain harvest as well as four weeks after grain harvest as influenced by cover crop and sowing time. At grain harvest, the highest cover crop growth was obtained from Italian Rye Grass sown on the same day, and the lowest cover crop growth was obtained from Meadow Fescue sown two weeks later. Four weeks after grain harvest, Italian Rye Grass sown obtained the highest cover crop growth on the same day, whereas Meadow Fescue sown two weeks later obtained the lowest cover crop growth. The biomass of wheat was found to be significantly higher than barley. Above-ground biomass yield of the cover crop was found to be statistically significant as influenced by cover crop and sowing time. The highest biomass was obtained from Italian Rye Grass sown on the same day. The lowest biomass was obtained from Meadow Fescue sown two weeks later. Grain yield of 15% moisture of barley was found to be significantly higher than wheat. Grain yield of 15% moisture was found to be statistically non-significant as influenced by cover crop and sowing time. Weed percentage was found to be statistically significant only when influenced by cover crop and their sowing time. The highest result was obtained from control and the smallest result was obtained from Italian Rye Grass sown on the same day. The interaction effect of main crops and cover crops and sowing time for weed percentage was found to be statistically significant. The highest result was recorded from the interaction of control and barley. In contrast, the lowest result was recorded from the interaction effect of Italian Rye Grass sown on the same day as wheat.

In the final conclusion, the following could be highlighted

- The cereal crop yield was not affected by the cultivation of cover crops. However, even better yield was obtained if perennial ryegrass and Italian ryegrass were used.
- Italian ryegrass sown on the same day as the grain showed the best growth and hence yielded the maximum dry matter, whereas meadow fescue sown two weeks after the grain performed the poorest, and cover crops could control the weeds by up to 83.05%.
- The yield of barley crops was higher than wheat, indicating the compatibility of barley crops with a cover crop.

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APPENDICES

Appendix 1. Details of soil physical and chemical properties of the experimental soil

ANALYSERAPPORT

AR-20-NF-013099-01

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Oppdragsnummer	EUNOMO4-00043371	**Kommunenr**	3403	**Prøvemottak**	03.12.2020	Side 1(3)
Kundenummer	NF0016590	**Gårdsnr**	67	**Analyserapport klar**	14.12.2020	
Prøvetype	Jordprøve	**Bruksnr**	1	**Rapportkommentar**		

Merking	Skifte	Volum-vekt	Jord-art	Leir-klasse	Mold	Mold-klasse	pH	* P-AL	P-klasse	* K-AL	K-klasse	* Mg-AL	* Ca-AL	* Na-AL	Gløde-tap	Tørr-stoff	TN	Ammo-nium -N	Nitrat -N	TOC	C/N	Tørr-stoff
		kg/l lufttørket			%TS			mg/100g lufttørket		mg/100g lufttørket		mg/100g lufttørket	mg/100g lufttørket	mg/100g lufttørket	%TS	% (w/w)	%TS	mg/100 g Ts	mg/100 g Ts	%TS		% (w/w)
H1	Blæstad																	0.73	8.5			79.7
H2	Blæstad																	1	6.2			79.9
H3	Blæstad																	0.74	5.93			81.4
H4	Blæstad																	0.4	6.9			82.2
H5	Blæstad																	1.4	8.57			79.8
H6	Blæstad																	0.86	8.31			81.7
H7	Blæstad																	0.93	7.71			79.8
H8	Blæstad																	0.49	7.46			90.9
H9	Blæstad	1.1	9	3	7.2	3	7.5	13	C2	7	1	8	550	6	9.2	79.1	0.33			4.5	14	
B1	Blæstad																	0.7	8.58			83.0
B2	Blæstad																	0.6	7.38			85.6
B3	Blæstad																	0.74	8.08			88.0
B4	Blæstad																	0.42	6.33			84.6
B5	Blæstad																	0.64	7.3			81.1
B6	Blæstad																	0.82	7.05			85.3
B7	Blæstad																	0.41	6.04			84.9
B8	Blæstad																	1.05	8.37			84.0

Jordarter

1 Grovsand	8 Silt
2 Mellomsand	9 Lettleire
3 Finsand	10 Siltig lettleire
4 Siltig grovsand	11 Mellomleire
5 Siltig mellomsand	12 Stiv leire
6 Siltig finsand	13 Mineralblandet moldjord
7 Sandig silt	14 Organisk jord

Leirklasser

1	< 5%
2	5 - 10%
3	10 - 25%
4	25 - 40%
5	> 40%

Moldklasser

1 Moldfattig	0 - 2,9%
2 Moldholdig	3 - 4,4%
3 Moldholdig	4,5 - 12,4%
4 Moldholdig	12,5 - 20,4%
5 Mineralbl.mold	20,5 - 40,4%
6 Organisk	> 40,4%

Næringsinnhold

	P-AL		K-AL	
Lavt	A	0 - 4	1	0 - 6
Middels	B	5 - 7	2	7 - 15
Moderat høyt	C1	8 - 10		
Høyt	C2	11 - 14	3	16 - 30
Meget høyt	D	>14	4	>30

* Ved volumvekt over 1.00 blir benevningen mg/100g. Ved volumvekt mindre enn 1.00 blir benevningen mg/100ml. For mikronæringsstoffer er benevningen alltid mg/kg

Appendix 2. Details of various weather parameters at the experimental site, Innlandet University College, Blæstad, Ridabu, Norway, from May to September 2019

Month	Weeks	Total weekly rainfall (mm)	Average relative humidity (%)	Average Maximum Temperature (˚C)	Average Minimum Temperature (˚C)
May	2	40.30	78.68	8.30	0.32
May	3	29.24	78.52	17.00	7.36
May	4	70.80	81.42	11.97	4.68
June	1	37.79	86.40	16.62	8.17
June	2	25.20	83.58	15.41	7.98
June	3	30.18	79.80	18.37	10.75
June	4	12.32	77.68	18.29	8.53
July	1	9.54	73.75	14.66	6.54
July	2	10.13	74.26	20.55	10.83
July	3	36.37	83.93	17.67	10.37
July	4	19.00	79.58	22.83	14.00
August	1	17.98	83.49	19.21	11.37
August	2	50.05	90.72	16.51	10.90
August	3	23.69	87.23	15.98	9.17
August	4	266.00	90.39	18.06	10.25

Appendix 3. Details of various weather parameters at the experimental site, Innlandet University College, Blæstad, Ridabu, Norway, from April to August 2020

Month	Weeks	Total weekly rainfall (mm)	Average relative humidity (%)	Average Maximum Temperature (˚C)	Average Minimum Temperature (˚C)
April	1	2.71	88.92	4.17	-3.40
April	2	9.14	84.56	3.71	-3.81
April	3	0.37	80.83	7.46	-2.95
April	4	18.32	81.98	6.69	-1.50
May	1	8.42	79.83	7.56	-1.20
May	2	6.58	72.50	6.18	-2.42
May	3	1.99	71.76	9.19	-0.57
May	4	21.15	77.45	15.40	5.47
June	1	53.76	79.48	16.43	10.04
June	2	7.65	74.56	18.79	8.54
June	3	11.51	74.26	24.51	14.62
June	4	49.32	81.07	21.37	13.16
July	1	53.63	79.86	13.25	6.10
July	2	22.66	78.71	14.96	6.66
July	3	30.53	86.08	17.20	10.19
July	4	37.35	81.61	16.91	7.65
August	1	16.70	84.75	18.49	10.71
August	2	7.63	82.09	21.65	12.52
August	3	17.56	82.99	21.62	13.42
August	4	20.78	82.55	14.86	6.47

Appendix 4. ANOVA table for Grain yield of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2019

```
Response:  Grain yield of wheat and barley
          Df Sum Sq Mean Sq F value  Pr(>F)
replication   2 116935   58468 19.3356 0.04917 *
mcrop        1  48192   48192 15.9375 0.05740 .
Ea           2   6048    3024  0.8842 0.59294
cctime       6  31736    5289  0.9649 0.47340
mcrop:cctime  6  32235    5373  0.9801 0.46423
Eb          20 109635    5482  0.8842 0.59294
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

cv(a) = 9.1 %, cv(b) = 12.3 %, Mean = 601.769
```

Appendix 5. ANOVA table for cover crop height at grain harvest of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2020

```
Response: cover crop height at harvest
          Df Sum Sq Mean Sq F value Pr(>F)
replication   2   4.50    2.25       1 0.5000
mcrop        1   2.25    2.25       1 0.4226
Ea           2   4.50    2.25
cctime       5  15.25    3.05       1 0.4430
mcrop:cctime  5  15.25    3.05       1 0.4430
Eb          20  61.00    3.05

cv(a) = 13.3 %, cv(b) = 15.5 %, Mean = 11.25
```

Appendix 6. ANOVA table for cover crop height after four weeks of grain harvest of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2020

```
Response: cover crop height 4 weeks after harvest
          Df Sum Sq Mean Sq F value    Pr(>F)
replication   2   3.72   1.861  0.1182   0.89432
mcrop        1 144.00 144.000  9.1429   0.09418 .
Ea           2  31.50  15.750
cctime       5 442.89  88.578 16.5911 1.622e-06 ***
mcrop:cctime  5  30.67   6.133  1.1488   0.36793
Eb          20 106.78   5.339
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

cv(a) = 23.5 %, cv(b) = 13.7 %, Mean = 16.88889
```

Appendix 7. ANOVA table for cover crop growth at harvest of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2020

Response: Cover crop growth at grain harvest

```
             Df  Sum Sq Mean Sq F value    Pr(>F)
replication   2   4.389  2.1944  6.0769   0.14130
mcrop         1   8.028  8.0278 22.2308   0.04216 *
Ea            2   0.722  0.3611
cctime        5 103.472 20.6944 19.2010 5.097e-07 ***
mcrop:cctime  5   2.806  0.5611  0.5206   0.75775
Eb           20  21.556  1.0778
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cv(a) = 17 %, cv(b) = 29.4 %, Mean = 3.527778
```

Appendix 8. ANOVA table for cover crop growth at four weeks after grain harvest of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2020

Response: Cover crop growth four weeks after harvest

```
             Df  Sum Sq Mean Sq    F value    Pr(>F)
replication   2   2.667  1.3333 2.6097e+29 < 2.2e-16 ***
mcrop         1   0.000  0.0000 8.6900e-02     0.796
Ea            2   0.000  0.0001
cctime        5 104.000 20.8000 3.1200e+01 8.649e-09 ***
mcrop:cctime  5   0.000  0.0000 0.0000e+00     1.000
Eb           20  13.333  0.6667
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cv(a) = 0 %, cv(b) = 22.3 %, Mean = 3.666667
```

Appendix 9. ANOVA table for above-ground dry matter yield of the cover crop at Innlandet University College, Blæstad, Ridabu, Norway, 2020

Response: Above ground dry matter yield

```
             Df  Sum Sq Mean Sq  F value    Pr(>F)
replication   2   27360   13680   5.8249   0.14652
mcrop         1  645256  645256 274.7438   0.00362 **
Ea            2    4697    2349
cctime        5 2428094  485619  16.0459 2.103e-06 ***
mcrop:cctime  5  369716   73943   2.4432   0.06971 .
Eb           20  605288   30264
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cv(a) = 11.1 %, cv(b) = 40 %, Mean = 435.3258
```

Appendix 10. ANOVA table for grain yield of wheat and barley at Innlandet University College, Blæstad, Ridabu, Norway, 2020

Analysis of Variance Table

Response: gyield

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
replication	2	2515230	1257615	1.5615	0.3904	
mcrop	1	15974877	15974877	19.8352	0.0469	*
Ea	2	1610762	805381			
cctime	6	339582	56597	1.4904	0.2237	
mcrop:cctime	6	273426	45571	1.2000	0.3401	
Eb	24	911395	37975			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cv(a) = 24 %, cv(b) = 5.2 %, Mean = 3738.354

Appendix 11. ANOVA table for weed percentage at harvest at Innlandet University College, Blæstad, Ridabu, Norway, 2020

Response: weed

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
replication	2	0.221	0.1103	0.0466	0.9555	
mcrop	1	12.098	12.0977	5.1097	0.1522	
Ea	2	4.735	2.3676			
cctime	6	41.998	6.9997	26.7608	1.647e-09	***
mcrop:cctime	6	5.521	0.9201	3.5176	0.0122	*
Eb	24	6.278	0.2616			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

cv(a) = 63.7 %, cv(b) = 21.2 %, Mean = 2.415968

BIOGRAPHICAL SKETCH

The author was born on 28th July November, 1994 in Patihani VDC of Chitwan district, Nepal. He is the son of Mr Bhabishwor Poudel and Mrs Ishwori Poudel. He passed his Secondary Level School from Blue Bird Secondary English School, Jagatpur, Chitwan, in 2010. He obtained Higher Secondary Level in Science (+2) from Orchid Science College, Bharatpur, Chitwan. The author completed Bachelor of Sciences in Agriculture (B.Sc.Ag.) at Agriculture and Forestry University (AFU), Rampur, Chitwan, in 2012. He currently is studying Master in Applied Ecology at Inland Norway University of Applied Sciences since 2019.

The author has worked as a B.Sc. Ag intern under Prime Minister Agriculture Modernization Project for five months. He was involved in various agriculture extension services, conducted various training and conducted a field laboratory service program. He has also worked as an enumerator to conduct the various household survey. He has also been involved in various social services like blood donation, flood relief, etc. He is also involved in non-profit organisations like Red Cross and LEO Club and acted as President of the Leo Club of Patihani in Leo year 2016/17. The author is fluent in Nepali, English and Hindi. He has a good command of the office suite (word processor, spreadsheet, presentation software) and photoshop. He has a good command of Excel, SPSS and other data analysis software.

He has a keen interest in agricultural research works and believes that agriculturists can play a prominent role in strengthening and revolutionising the nation's agriculture scenarios. He is a simple, gentle and diligent optimistic person. The author is single in marital status and has a blissful time with his family.

Author