Slim Landgebruik

Cover crop reference values

Effective organic matter and nitrogen uptake

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Colofon

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Summary: Reference value for effective organic matter (EOM) values are used for calculating the organic matter addition to the soil. In order to update and supplement EOM reference values of cover crops, biomass data was gathered and an experiment was conducted to determine the humification coefficient, which is used to calculate the EOM. The results do not lead to a change in the current humification coefficient values. For ten monoculture cover crops model-based EOM and nitrogen uptake reference values are given in tables per half a month. For some species reference values were also given per 10 cm crop height.

Keywords: reference values, effective organic matter, cover crops, nitrogen uptake, humification coefficient, sowing time, crop height

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Preface

In this report we update and supplement the reference values for effective organic matter and nitrogen uptake of cover crops. This research was initiated by the *Ministry of Agriculture, Nature and Food Quality (LNV)* programme *Slim Landgebruik*, which focuses on how soils can be sustainably used for carbon sequestration. It was conducted by Wageningen Research in close collaboration with the *PPS Beter Bodembeheer* with funding from the *Topsector Agri & Food* and *BO Akkerbouw*.

In the period of 2018-2021 many have contributed to this research:

- Wageningen University & Research - Field Crops: Maria-Franca Dekkers, Wiepie Haagsma, Marie Wesselink, Marjoleine Hanegraaf, Jan Tolhoek, Oane de Hoop, Wim van den Berg and the managers and employees of the experimental farms in Vredepeel, Lelystad, Valthermond and Westmaas
- Our interns: Kimberly van der Vegt, Annemiek Hogendoorn en Jurrian de Lange
- Other organizational units Wageningen University & Research: Sabine Schnabel (BIOMETRIS) for statistical analysis and Willeke van Tintelen (CBLB) for the execution of the incubation experiments.
- Nutriënten Management Institute (NMI): Romke Postma and Imke Harms for the literature study and report in 2018.

The full dataset will be made available at the data portal of the WUR in 2021.

Summary

Introduction

Organic matter management is important to maintain soil quality and productivity. By making up an organic matter balance a farmer or advisor can estimate whether the management is satisfactory. One approach is the use of reference values for effective organic matter (EOM) for manure, crops and cover crops. The EOM is the amount of organic matter (OM) still present in the soil one year after incorporation. It is calculated by taking the dry matter biomass minus the ash content, multiplied by the humification coefficient (HC), which is the fraction OM still present after one year. In this report we updated and supplemented the current EOM reference values for ten green manure crops. We also provide reference values for nitrogen (N) uptake by the cover crop based on the same dataset.

Materials and methods

Field data of OM of cover crops was gathered from international literature, previous experiments and sampling in 2018 and 2019. In order to update the HC's, an incubation experiment was performed, where carbon mineralization was measured to estimate decomposition.

Results

Humification coefficients

The experiment for determining the HC resulted in a set of values with a large variation. The average HC for leaves was 0.32 and 0.36 for roots. The current reference values are 0.2 and 0.35 respectively. Due to the large variation in the data no reliable distinction could be made per plant part, species or for different developmental stages. It was concluded to use the current reference values for calculating the EOM and that another method and/or more measurements will be needed to update these values.

Factor analysis

Factor analysis on aboveground OM across all species showed that sowing week number is a better predictor than temperature sum and radiation, after cover crop species and crop height. Additional factors, such as soil type, N fertilisation and moisture levels were significant as well. However, due to missing values, marginal or varying effects and a poor spread of the data over different soil types and fertilisation levels, these were not included to make further distinctions in the reference values. Because the data on belowground biomass was very limited, we chose to use the shoot:root ratio to be able to estimate the total OM for all entries of aboveground OM. The best predictor variable of shoot:root OM ratio was the aboveground OM.

Model selection

Using the best predictor variable per response variable (OM aboveground, shoot:root OM ratio, N uptake aboveground, shoot:root N uptake ratio), a simple model was fit to each species separately. The predictions for the shoot:root OM ratio and shoot:root N uptake ratio were used with the predictions for aboveground OM and N uptake to calculate the belowground OM and N uptake. Total EOM and N uptake per species was calculated per half month (Table 1 and Table 3). For some crops, where a relation with crop height was found, EOM reference values based on crop height were determined per 10 cm (Table 2 and Table 4).

Table 1. The reference values based on sowing time in kg EOM per ha, predicted by the models.

<table>
<tr><th></th><th colspan="7">Sowing time</th></tr>
<tr><th>Crop</th><th>15-Jul</th><th>01-Aug</th><th>15-Aug</th><th>01-Sep</th><th>15-Sep</th><th>01-Oct</th><th>15-Oct</th></tr>
<tr><td>Winter rye</td><td colspan="5">800</td><td>650</td><td>400</td></tr>
<tr><td>Black oats</td><td>-</td><td>1650</td><td>1000</td><td>550</td><td>400</td><td>350</td><td>300</td></tr>
<tr><td>Common vetch</td><td>800</td><td>700</td><td>500</td><td>350</td><td>250</td><td>-</td><td>-</td></tr>
<tr><td>Fodder radish</td><td>2050</td><td>1600</td><td>950</td><td>650</td><td>350</td><td>150</td><td>-</td></tr>
<tr><td>Italian ryegrass</td><td>1850</td><td>1600</td><td>1250</td><td>1000</td><td>750</td><td>450</td><td>200</td></tr>
</table>

Phacelia	-	1100	600	350	150	50	-
Tall fescue	-	-	-	-	1050		-
White mustard	*1800*	1250	750	500	350	250	-
Winter barley	-	-	-	650			300
Tagetes	*2500*	1350	1200	-	-	-	-

Table 2. The reference values based on crop height in kg EOM per ha, predicted by the models.

	Crop height (cm)														
Crop	***10***	***20***	***30***	***40***	***50***	***60***	***70***	***80***	***90***	***100***	***110***	***120***	***130***	***140***	***150***
Black oats	-	-	-	500	600	650	750	850	1000	1100	1250	1400	1500	1700	1850
Common vetch	-	250	450	550	-	-	-	-	-	-	-	-	-	-	-
Fodder radish	100	250	400	550	700	850	1000	1150	1250	1400	1500	1600	1700	1800	1900
Phacelia	-	150	300	450	600	700	800	900	1000	-	-	-	-	-	-
White mustard	150	200	200	250	300	350	400	450	500	550	650	750	850	950	1100
Tagetes	-	-	-	-	-	-	1150	1200	1250	1350	1500	1650	1900	2150	2500

Table 3. The reference values based on sowing time in kg N per ha, predicted by the models.

	Sowing time						
Crop	***15-Jul***	***01-Aug***	***15-Aug***	***01-Sep***	***15-Sep***	***01-Oct***	***15-Oct***
Winter rye	-	-	-	-	75	55	40
Black oats	-	115	75	45	40	35	25
Common vetch	-	-	-	-	95	-	-
Fodder radish	240	175	110	80	55	40	-
Italian ryegrass	-	-	-	-	-	40	-
Phacelia	-	90	50	40	30	20	-
Tall fescue	-	-	-	-	40		-
White mustard	145	120	95	80	65	55	-
Winter barley	-	-	-	40			20
Tagetes	125			-	-	-	-

Table 4. The reference values based on crop height in kg N per ha, predicted by the models

	Crop height (cm)									
Crop	***10***	***20***	***30***	***40***	***50***	***60***	***70***	***80***	***90***	***100***
Black oats	20	35	45	55	60	70	75	80	80	85
Common vetch	-	65	-	-	-	-	-	-	-	-
Fodder radish	25	35	45	55	75	100	125	165	215	280
Phacelia	-	25	40	55	70	85	90	90	90	-

Discussion and conclusions

Due to a heterogeneous dataset, several interactions and missing values, the influence of factors such as soil type, N fertilisation and soil mineral N could not be satisfactorily evaluated. Additionally, the model that was fitted was not satisfactory for some species. We therefore recommend that targeted additional sampling is done, in order to further substantiate and refine the reference values.

Samenvatting

Introductie

Goed beheer van de bodem organische stof (OS) is belangrijk om de bodemkwaliteit te bewaren. Met een organische stofbalans kan een agrariër of adviseur een inschatting maken of het organische stof aanvoer voldoende is. Een methode om de balans op te stellen is het gebruik van kengetallen van effectieve organische stof aanvoer (EOS) van mest, gewasresten en groenbemesters. De EOS is de hoeveelheid van het OS wat in de bodem nog aanwezig is één jaar na onderwerken. Het wordt berekend de droge stof (minus ruw as) te vermenigvuldigen met de humificatiecoëfficiënt (HC), dit is de fractie van de OS wat nog niet afgebroken is één jaar na onderwerken. In dit rapport worden de huidige EOS-kengetallen voor tien groenbemesters geactualiseerd en aangevuld. We geven ook nieuwe kengetallen aan voor de stikstofopname van de groenbemesters.

Materiaal en methode

Data uit veldmetingen werd verzameld uit internationale literatuur, eerdere experimenten en bemonsteringen in 2018 en 2019. Daarnaast werd een incubatie experiment werd uitgevoerd waarbij koolstofmineralisatie gemeten werd om de HC te berekenen.

Resultaten

Humificatiecoëfficiënten

Het incubatie experiment resulteerde in een dataset met een grote spreiding. De gemiddelde HC was voor blad 0,32 en voor wortels 0,36. De huidige kengetallen hiervoor zijn 0,2 en 0,35, respectievelijk. Door de grote variatie in de data was het niet mogelijk om een onderscheid te maken in de HC tussen blad en wortel, verschillende soorten of ontwikkelingsstadium. De keuze werd gemaakt om de huidige kengetallen van HC te gebruiken voor het bepalen van de EOS. Het advies is om meer metingen uit te voeren of om een andere methode toe te passen om tot actualisatie van HC-kengetallen te komen.

Factoranalyse

De factoranalyse van de bovengrondse OS over alle soorten heen toonde dat zaaiweek een betere voorspeller is dan temperatuursom en straling, na de factoren groenbemestersoort en gewashoogte. Aanvullende factoren, zoals grondsoort, stikstofbemesting en vochtbeschikbaarheid waren significant, maar door de grote hoeveelheid ontbrekende cijfers, relatief kleine en variabele effecten en een slechte spreiding van de data over verschillende grondsoorten en bemestingsniveaus, werd deze niet gebruikt voor verdere onderscheid in de kengetallen. Doordat er weinig data beschikbaar was van de ondergrondse OS, werd de ratio van bovengrondse:ondergrondse biomassa gebruikt om een inschatting te kunnen maken van de totale OS van alle data van bovengrondse OS. De beste voorspellende variabel voor de ratio van bovengrondse:ondergrondse biomassa was de bovengrondse OS.

Modelselectie

Gebruikmakend van de beste voorspellende variabel per responsvariabel (OS bovengronds, ratio bovengrondse:ondergrondse OS, N opname bovengronds, ratio bovengrondse:ondergrondse N opname), werd een simpel model gefit per soort. De voorspellingen van de ratio bovengrondse:ondergrondse OS en ratio bovengrondse:ondergrondse N opname werd gebruikt met de predicties voor bovengrondse OS en N opname om de ondergrondse OS te berekenen. De totale EOS en N opname werd per soort berekend per halve maand (Tabel 5 en Tabel 7). Voor enkele soorten, waarbij een verband tussen OS en gewashoogte duidelijk was, werd EOS-kengetallen opgesteld per 10 cm gewashoogte (Tabel 6 en Tabel 8).

Tabel 5. De kengetallen gebaseerd op zaaitijdstip in kg EOS per ha.

	Zaaitijdstip						
Soort	***15-Jul***	***01-Aug***	***15-Aug***	***01-Sep***	***15-Sep***	***01-Okt***	***15-Okt***
Winterrogge	800					650	40

Japanse haver	-	1650	1000	550	400	350	300
Wikke	*800*	700	500	350	250	-	-
Bladrammenas	*2050*	1600	950	650	350	150	-
Italiaans raaigras	*1850*	1600	1250	1000	750	450	200
Facelia	-	1100	600	350	150	50	-
Rietzwenkgras	-	-	-	-	1050		-
Gele mosterd	*1800*	1250	750	500	350	250	-
Wintergerst	-	-	-	650			300
Tagetes	*2500*	1350	1200	-	-	-	-

Tabel 6. De kengetallen gebaseerd op gewashoogte in kg EOM per ha.

	Gewashoogte (cm)														
Soort	***10***	***20***	***30***	***40***	***50***	***60***	***70***	***80***	***90***	***100***	***110***	***120***	***130***	***140***	***150***
Japanse haver	-	-	-	500	600	650	750	850	1000	1100	1250	1400	1500	1700	1850
Wikke	-	250	450	550	-	-	-	-	-	-	-	-	-	-	-
Bladrammenas	100	250	400	550	700	850	1000	1150	1250	1400	1500	1600	1700	1800	1900
Facelia	-	150	300	450	600	700	800	900	1000	-	-	-	-	-	-
Gele mosterd	150	200	200	250	300	350	400	450	500	550	650	750	850	950	1100
Tagetes	-	-	-	-	-	-	1150	1200	1250	1350	1500	1650	1900	2150	2500

Tabel 7. De kengetallen gebaseerd op zaaitijdstip in kg N per ha.

	Zaaitijdstip						
Soort	***15-Jul***	***01-Aug***	***15-Aug***	***01-Sep***	***15-Sep***	***01-Okt***	***15-Okt***
Winterrogge	-	-	-	-	75	55	40
Japanse haver	-	115	75	45	40	35	25
Wikke	-	-	-	-	95	-	-
Bladrammenas	240	175	110	80	55	40	-
Italiaans raaigras	-	-	-	-	-	40	-
Facelia	-	90	50	40	30	20	-
Rietzwenkgras	-	-	-	-	40		-
Gele mosterd	145	120	95	80	65	55	-
Wintergerst	-	-	-	40			20
Tagetes	125			-	-	-	-

Tabel 8. De kengetallen gebaseerd op gewashoogte in kg N per ha.

	Gewashoogte (cm)									
Soort	***10***	***20***	***30***	***40***	***50***	***60***	***70***	***80***	***90***	***100***
Japanse haver	20	35	45	55	60	70	75	80	80	85
Wikke	-	65	-	-	-	-	-	-	-	-
Bladrammenas	25	35	45	55	75	100	125	165	215	280
Facelia	-	25	40	55	70	85	90	90	90	-

Discussie en conclusies

Door een heterogene dataset, ontbrekende data en interacties, konden de factoren zoals grondsoort, N-bemesting, N-mineraal bodem niet volledig geëvalueerd worden. Daarnaast is het model niet voor alle soorten goed onderbouwd of is het verband slecht. Er wordt daarom geadviseerd om meer gegevens te verzamelen, van bepaalde groenbemestersoorten en onder specifieke omstandigheden, om de kengetallen verder te onderbouwen en te verbeteren.

1 Introduction

Management of the organic matter input to the soil is key for maintaining soil quality and durable crop production. Soil organic matter (SOM) contributes to soil fertility and crop growth by numerous ways such as the binding and buffering of plant nutrients (Murphy, 2015), providing habitat and food for soil organisms (Sapkota et al., 2012; Aldebron et al., 2020), maintaining soil moisture (Lipiec et al., 2006) and improving the soil structure (Masri & Ryan, 2006; Simansky et al., 2013). Besides these functions, SOM is a form of carbon sequestration and is therefore important for mitigating greenhouse gas emissions (Lal, 2004; Iranmanesh & Sadeghi, 2019). Organic matter (OM) is added to the soil by organic manures and crop residues and leaves the soil by mineralization due to decomposition. Cover crops provide an additional source of OM (Ding et al., 2006) and have recently become compulsory to grow in the Netherlands after corn and potato, in order to decrease nutrient leaching (Fan et al., 2020). Other functions of cover crops are to protect the soil for prevention of weed growth and erosion (Brust et al., 2014; de Beast et al., 2011), improving soil structure (Restovich et al., 2019), providing habitat and food for organisms (Rutgers et al., 2010; Ellis & Barbercheck, 2015) and to decrease soil pathogens (Hooks et al., 2010; Larkin, 2013). After incorporation and decomposition of the cover crop, some of the nutrients taken up will become available for the succeeding crop which benefits its growth (Fowler et al., 2004; Rinnofner et al., 2008). In recent years, there is an increasing interest of farmers and researchers in the use of cover crop species mixtures. The advantages of a mixture is the varying rooting pattern that can improve soil structure (Fageria et al., 2005; Kinderiene, 2009) and the diverse habitat for biodiversity (Dahlin et al., 2018).

1.1 Effective organic matter

An organic matter (OM) balance is calculated to get an overview of the inputs and outputs of organic matter. The effective organic matter (EOM) of a crop refers to the amount of OM from the crop residues, that is still present in the soil one year after it was incorporated. For calculating the OM balance the EOM is used, because it indicates the potential for build-up of OM in the longer term. The concept of EOM was developed for North-West European climatic conditions with an average year temperature of 9 ℃ and is used in The Netherlands and Germany (VDLUFA, 2014 ; CBAV, 2019). Reference values for EOM addition have long been available for many crops as well as a small number of cover crops (Table 9). The EOM values are calculated by subtracting the ash content from the dry matter production of the crop and multiplying this by the humification coefficient (HC), which is the fraction of OM that is still present one year after incorporation (e.g. De Haan, 1977). The ash content is either measured or estimated to be 10% of the dry matter production and refers to all non-combustible components of plant matter. The HC is currently assumed to be 0.2 for fresh green aboveground biomass and 0.35 for roots and is used as an input parameter in the AMC-model (Clivot et al., 2019) and in RothC (Dechow et al., 2019).

Table 9. Current reference values for EOM in kg EOM/ha of nine cover crops. Sources for these reference values are: PAGV (1989), Handboek groenbemesters (2019) and 'Handboek bodem en bemesting 2018c'. Due to different sources, the total is not always calculated from the given above- and belowground values.

Species	Aboveground EOM	Belowground EOM	Total above- and belowground EOM
Black oats	320	-	850
Common vetch	500	175	650
English ryegrass	440	700	1150
Fodder radish	620	280	875
Italian ryegrass	500	595	1100
Tagetes	1200	-	625
Tall fescue	400	700	1100
Winter rye	200	210	850
White mustard	620	280	875

Conijn and Lesschen (2015) compared humification coefficients from various sources, and concluded that differences in HC's have only been reported for belowground biomass. For aboveground biomass the authors concluded that most literature refers back to the same source. The current reference values are based on long-term field experiments (+10 years) from more than 50 years ago (Kortleven, 1963 ; Kolenbrander, 1969). During the last decades, a common method for determining decomposition rates are incubation experiments where CO_2 respiration is measured (Groenigen & Zwart, 2007; Lashermes et al., 2009; Jäger et al., 2013; Cotrufo et al., 2015; Mewes, 2017; Mondini et al., 2017). This method has been applied in several studies on decomposition of organic manures, where also HC's have been calculated (Postma & Ros, 2016 ; Groenigen & Zwart, 2007 ; Van den Burgt et al., 2011 ; VLACO, 2015 ; Reinhold et al., 2016 ; CDM, 2017, Rietra et al., in press).

1.2 Research objectives and questions

The reference values for EOM input by cover crops need to be updated and supplemented, since the current values originate from outdated and limited measurements from before the 1990's (PAGV, 1989). During the last 40 years, new cover crop species and varieties have been introduced and breeding may have increased biomass production and influenced shoot:root ratios. More importantly, the sowing time has a large impact on the OM production and the current reference values do not take this into account. In this study we gathered data to establish new reference values for the EOM addition of cover crops, as well as their nitrogen (N) uptake. Although data was gathered from mixtures, we limit our analysis to monoculture cover crops. Furthermore, we performed incubation experiments where we determined the HC's for shoots and roots. The expectation was to see a difference between plant part, plant species and between growth stages, due to differing chemical composition. This report is elaborating further on the report about cover crop reference values by Harms et al. (2018). The research questions we answer in this report are:

Humification coefficients:

1. Do the derived HC's differ between cover crop species?
2. Do the derived HC's differ from the current reference values of 0.2 for shoots and 0.35 for roots?
3. Do the derived HC's differ between different plant development stages?

Reference values for EOM and N uptake by cover crops:

4. Which factors predict the OM production and N uptake of cover crops?
5. Which reference values for OM production and N uptake of cover crops can be used? Do the new values differ from the current reference values?

2 Materials and methods

2.1 Carbon respiration experiment

Two incubation experiments with measurements of carbon respiration were performed to determine the humification coefficients of seven cover crops. The species that were incubated were fodder radish, black oats, common vetch, tagetes, and white mustard. Additionally, a mixture (mixture-3) was incubated, consisting of fodder radish, black oats and common vetch, as well as a mixture called SolaRigol (mixture-12), consisting of eight species: common vetch, black oats, fodder radish, Niger, flax, berseem clover, Ethiopian mustard and camelina. The shoot and root were incubated separately in two repetitions. Each cover crop was incubated in two growth stages with approximately 50 growing days difference (Table 20). Treatments "less developed" and "more developed" refers to the age or development stage of the crop and not to a stunted growth due to poor growing conditions. For reference, leaves of English ryegrass (considered to be a good representative for green aboveground biomass with a current HC value of 0.20) and wheat straw (with current HC value of 0.30, considered to be higher than the HC of green aboveground biomass) were also included.

The experiment was performed in two separate series with different crop materials in each series (' gg ggg 21). For the laboratory measurements the protocol was followed as is described by van Dijk (2005) and Van der Burgt et al., (2011), unless stated otherwise. The CBLB - WUR laboratory protocol was WUR SOP NO: 0003. The crop residues were dried at 70 °C for 24 hours and subsequently ground into powder. A sandy soil classified as a Haplic podzol was sampled in November 2019 at the experimental farm of Wageningen University & Research (51.992503, 5.662114). The soil was sieved with 5 mm precision and subsequently dried at 40 °C. Crop residues and soil were analysed for C and N concentration, using the LECO 19.30+1.10+1.10 method. Soil mineral N was not determined and also no additional N was added to prevent N immobilization. Approximately 1 gram of crop residue was incubated in 150 g of soil in a glass vial based on the same amount of C. The amount of cover crop residue added corresponded to an amount that is multiple times higher than that under field conditions, which is common in these incubation experiments. Two vials with only soil were incubated to determine the CO_2 flux originating from the soil itself. At all times, the soil moisture was kept at 60% of the water holding capacity and the temperature at 20 °C. In both experiments, the respiration of carbon dioxide was measured at day 1, 7, 14, 28, 58 and 84 whereas for the second experiment it was also measured at day 112 and 140. Measurement was done after keeping the vial closed for a short amount of time. The respiration was averaged for the two repetitions. Subsequently, the respiration was integrated and the amount of decomposed C for each period between the measurements was calculated. Thereafter, the remainder amount of C was calculated and expressed as a percentage of the initial amount. The decomposition rate of C during the respiration period was described by fitting a double-exponential model, using the statistical package Genstat 19th ed. From earlier respiration laboratory experiments it is known that this model performs well (Groenigen & Zwart, 2007; Van der Burgt et al., 2011). The equation in Genstat is: $B*R^t + C*S^t$, which is similar to: $B*e^{-k1t} + C*e^{-k2t}$, as $R = e^{-k1t}$ and $S = e^{-k2t}$. The HC was calculated as the remaining fraction after one year with an average annual temperature of 9 °C. The correction for the effect of temperature on the decomposition rate was made according to Janssen (1996):

$$f_T = 2^{\left(\frac{(T-9)}{9}\right)}$$

2.2 Organic matter data sources

2.2.1 Database description

Data were gathered from new field measurements, available data from previous years and by literature study of international scientific and grey literature. Additional information was gathered about the cover crops and their growing conditions, such as variety, country, location, soil type, pre-crop, N fertilization (kg/ha), sowing date, sampling date, temperature sum, radiation sum (MJ/m^2), moisture availability (precipitation minus evapotranspiration in mm), seeding rate per species (kg/ha) and mineral N in the soil (kg/ha) after harvest, before winter and at moment of termination of the cover crop. Temperature sum was calculated with a base temperature of 5°C. For undersown crops the harvesting date of the pre-crop was used as starting date for calculating the weather variables. When the OM data was not available but only the dry matter, due to lacking information on ash content, we assumed the OM to be 90% of the dry matter. For all data entries, we assume the sampling was done before over-ripening of the crop and before regrowth in springtime. Growth during the winter months is assumed to be negligible. In total, 1586 data points were gathered from field measurements, literature study and compiled own data. In the data analysis of this report we excluded the data of mixtures, as well as species with too few data points, resulting in 1233 data points in total for the aboveground OM. The species for which we present reference values are black oats, common vetch, fodder radish, Italian ryegrass, phacelia, tagetes, tall fescue, white mustard, winter barley and winter rye. See Table 22 for an overview of the different data sources.

2.2.2 Literature study

Data on cover crops were collected from around 15 different international scientific and grey literature from the years 1992-2015 (Harms et al. 2018). Selection was based on countries with similar climatic conditions and crop yields as in the Netherlands. In total 163 data points were gathered from the countries Belgium, Germany, Switzerland, Denmark, France and UK. Nearly all data points were from a sandy or loamy soil. The methodology for sampling used in these studies is variable, however it is assumed that use for comparison is suitable as biomass determination is a simple procedure.

2.2.3 Data compilation

Data was gathered from previously executed experiments within the organization from the period 1989-2019. Several of these were multi-year experiments with repetitions at one to three locations. The methodology is in principle the same as described below in 2.2.4 but has not further been examined as we assume that they are comparable. In total 760 measurements were gathered in this way.

2.2.4 Field measurements

In the growing seasons of 2018 and 2019 measurements were made in a variety of different cover crop experiments, as well as in farmer fields, on three different soil types; sand, clay and reclaimed peat soil. When sampling in experiments, all repetitions of the treatment were sampled, generally resulting in four samples. Farmer fields were sampled at 4 representative spots. Before sampling, the height of the cover crop was determined in cm above soil level. In mixtures, the highest species determined the crop height. Aboveground biomass from an area of 0.25 m^2 was cut at 1-3 cm above the ground and subsequently dried at 70 °C for at least 24 hours, after which it was weighed to determine the dry matter biomass. Within the same 0.25 m^2 plot 6 soil cores with a diameter of 8 cm were sampled until 30 cm depth, 3 diagonally within the row on top of the crop and 3 diagonally between the rows. Subsequently the cores were rinsed from soil, dead organic matter and stones. The remaining roots were dried and weighed. Cores from the depth 15-30 cm were not rinsed if there were none or a negligible amount of roots present determined by visual assessment. The samples were thereafter analysed for ash, N, P, K and micro-nutrient concentration using accredited and certified methods (Eurofins, 2020). In total 663 data points were gathered following this methodology.

2.3 Data analysis

2.3.1 Humification coefficients

For research question 2. and 3. normality was tested with a Shapiro-Wilk test followed by a one-sample t-test and a paired two samples t-test, respectively. The one-sample t-test was also performed with exclusion of the outliers. A regression analysis was performed with Genstat following the RSEARCH procedure for obtaining the best-fitting model. Subsequently, a REML variance component analysis was performed to determine the effects of the factors; species, development stage, plant part and incubation series. The REML procedure was executed twice, with the second time excluding the data point Mixture-12 root as it was an outlier in both series, but this did not change the significances of the analysis. In the results section the results from the first round are presented. For all testing of significance an $\alpha=0.05$ was used.

2.3.2 Organic matter and nitrogen uptake

Analysis was done in RStudio (RStudio Team, 2020) using α=0.05 for statistical testing. It focused on four response variables; aboveground OM production, aboveground N uptake, shoot:root OM ratio and the shoot:root N uptake ratio. Because the data on belowground biomass was very limited we chose to use the shoot:root ratio to be able to estimate the total OM and N uptake for all entries where aboveground values were available. All four response variables were log-transformed for the factor (step 1) analysis in order to fulfil the assumption of normal distribution. The process of establishing new reference values was the following:

1. The best predictor variable(s) for each of the response variables across all species was determined by exploring generalized linear models and type III ANOVA (Wald) tests.
2. Per species and response variable, the best fitting linear, polynomial, exponential or broken stick model (with one joint) was selected according to adjusted R squared and visual assessment, using the best predictors selected in step 1. R-squared values of the broken stick models with a non-significant slope for one segment are given for the model assuming two slopes and not a horizontal line. Here we excluded the literature data.
    a. When no model could be satisfactorily fitted (inclination coefficient not significantly different from 0 or a poor visual fit) we fitted a horizontal line.
    b. When neither a model nor a horizontal line could be fitted we made manual calculations for one or more averages.
3. The predictions given by the model for aboveground OM production and N uptake in a range of weeks were retrieved.
4. Using the output from step 3, predictions from the models for shoot:root ratio were retrieved.
5. Belowground OM and N uptake were calculated by dividing the aboveground OM and N uptake by the shoot:root ratio predictions from step 4.
6. Above- and belowground OM and N uptake values were summed to provide the total OM and N uptake. For EOM output, here the aboveground values were multiplied by 0.2 and the belowground values by 0.35 (see paragraph 3.1).
7. The EOM production and N uptake per species calculated per week were rounded to the nearest 50 kg EOM/ha or 5 kg N/ha, respectively. We provided one value for the 1st and 15th of every month in a reference value table. For species where the model had a poor fit or the amount of data was small, one value is provided for a larger period (e.g. winter rye and winter barley).

A similar process was followed for predicting OM production and N uptake based on crop height. A model was fit to the relation between crop height and aboveground OM production or N uptake for those crops where a relationship was apparent. The aboveground OM production and N uptake was predicted per 10 cm of crop height. Thereafter the model for shoot:root ratio was used to calculate the belowground OM production and N uptake. The results are given per 10 cm for the heights 10-150 cm, depending on the species.

3 Results

3.1 Humification coefficients

The two repetitions of each crop material had very similar CO_2 fluxes, while the variation was large between the different plant parts and cover crop species (Table 10 and Figure 5. Correlation table for numerical variables. Blue dots stand for a significant positive correlation and red dots for a significant negative correlation. The size of the dot indicates the strength of the correlation. The dataset contained three extreme outliers and one of the derived HC is deemed unreliable due to poor model fit.

Table 10. Derived humification coefficients of above- and belowground cover crop biomass for a more developed and a less developed crop. The indicated range of the across-crop averages is the 95% confidence interval. Extreme outliers are marked in red and values derived with a poor model fit in orange.

Plant part	Cover crop	Less developed	More developed	Average
Shoot biomass	White mustard	0.39	0.37	0.38
	Fodder radish	0.31	0.26	0.29
	Common vetch	0.29	0.20	0.25
	Black oats	0.31	0.41	0.36
	Tagetes	0.26	0.37	0.32
	Mixture-3	0.30	0.37	0.34
	Mixture-12	0.32	0.32	0.32
	Average	**0.31 ± 0.02**	**0.33 ± 0.05**	**0.32 ± 0.03**
Root biomass	White mustard	0.39	0.43	0.41
	Fodder radish	0.14	0.40	0.27
	Common vetch	0.48	-	0.48
	Black oats	0.44	0.36	0.40
	Tagetes	0.25	0.47	0.36
	Mixture-3	0.19	0.49	0.34
	Mixture-12	0.05	0.65	0.35
	Average	**0.28 ± 0.11**	**0.47 ± 0.07**	**0.36 ± 0.09**

The straw and English ryegrass leaves that were used as references had humification coefficients of 0.4 and 0.29, respectively. The derived humification coefficients had a total average of 0.34 (95% CI ± 0.04) with an average of 0.32 for shoot biomass and 0.36 for root biomass (Table 10. Derived humification coefficients of above- and belowground cover crop biomass for a more developed and a less developed crop. The indicated range of the across-crop averages is the 95% confidence interval. Extreme outliers are marked in red and values derived with a poor model fit in orange.). When excluding outliers, the average for root biomass is 0.43 (95% CI± 0.07).

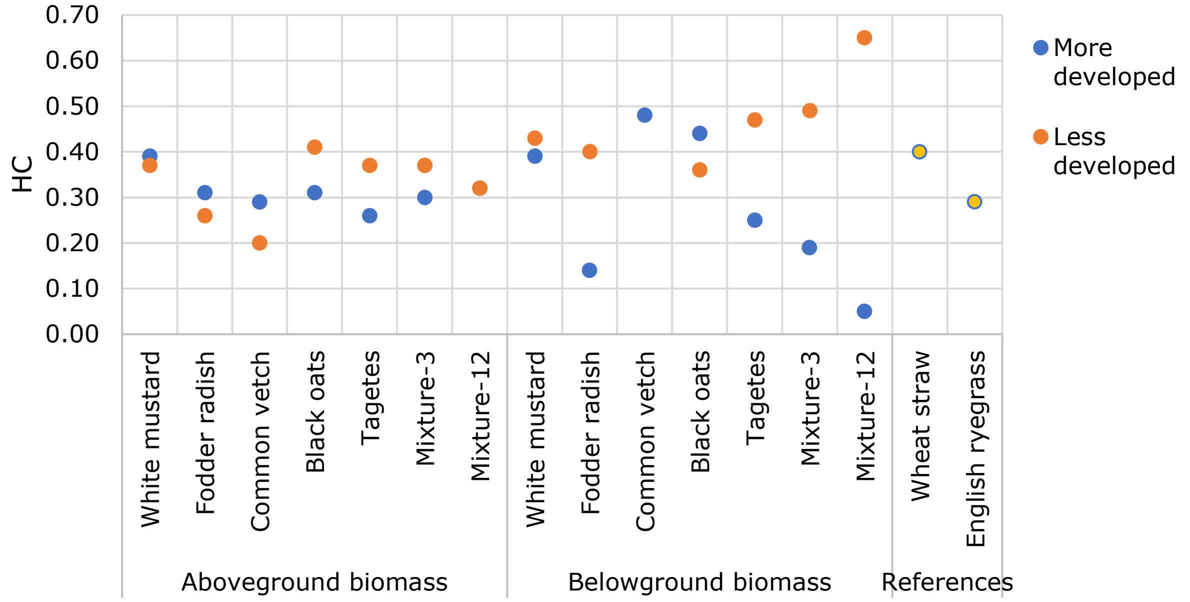

Figure 1. Scatterplot of derived humification coefficients of above- and belowground cover crop biomass for a more developed crop (blue) and a less developed crop (orange).

Regression modelling with RSEARCH shows development as a significant factor (p=0.008) while species (p=0.943), plant part (p=0.388) and incubation series (p=0.218) were not significant factors. The REML analysis also shows development as a significant factor (p=0.008) while species (p=0.905) and plant part (p=0.388) were not significant factors. No interactions were found between the factors in the analyses.

When bundling the data of the different species together, the derived average HC for shoot biomass of 0.32 is significantly higher than the current value of 0.20 (Two-tailed p=0.00, One-sample t-test, n=15). For root biomass the HC of 0.36 is not significantly different from the current value of 0.35 (Two-tailed p=0.75, One-sample t-test, n=13). When excluding the outliers in the root data, giving an average of 0.43, the outcome is the same (Two-tailed p=0.09, One-sample t-test, n=9).

More developed crop material had an average value of 0.31 (95% CI ± 0.04) for shoot biomass and 0.28 (95% CI ± 0.11) for root biomass, compared to less developed crop materials with 0.33 (95% CI ± 0.05) for shoot biomass and 0.47 (95% CI ± 0.07) for root biomass. The averages of the two development stages are not significantly different for shoot biomass (Two-tailed p=0.58, Paired t-test, n=7) or root biomass (Two-tailed p=0.07, Paired t-test, n=6), however there is a trend for a higher HC for more developed root material (p=0.07). When used as a factor in the regression model the development stage is a significant factor with a predicted average HC for more developed material of 0.31 and for less developed material 0.44.

3.2 Organic matter and nitrogen uptake

3.2.1 Data description

The number of available datapoints varies largely dependent on species and response variable (Table 24. The number of observations of each species. Excluding literature data.). The OM production data showed a large variation (Figure 2. The spread of the data of the aboveground OM production for all species. The number indicates the number of data entries. and Figure 3. The spread of the data of the belowground OM production for all species. The number indicates the number of data entries.. The majority of the data came from a sandy soil type (Figure 7. The number of observations of each species per soil type. Including literature data.). The most common pre-crops were potato and corn (Figure 6. The number of observations per crop and pre-crop combination. Including literature data.). In Figure 4. The average and standard deviation per cover crop species for shoot and root OM in kg per ha. the allocation to shoot and root biomass is depicted per species.

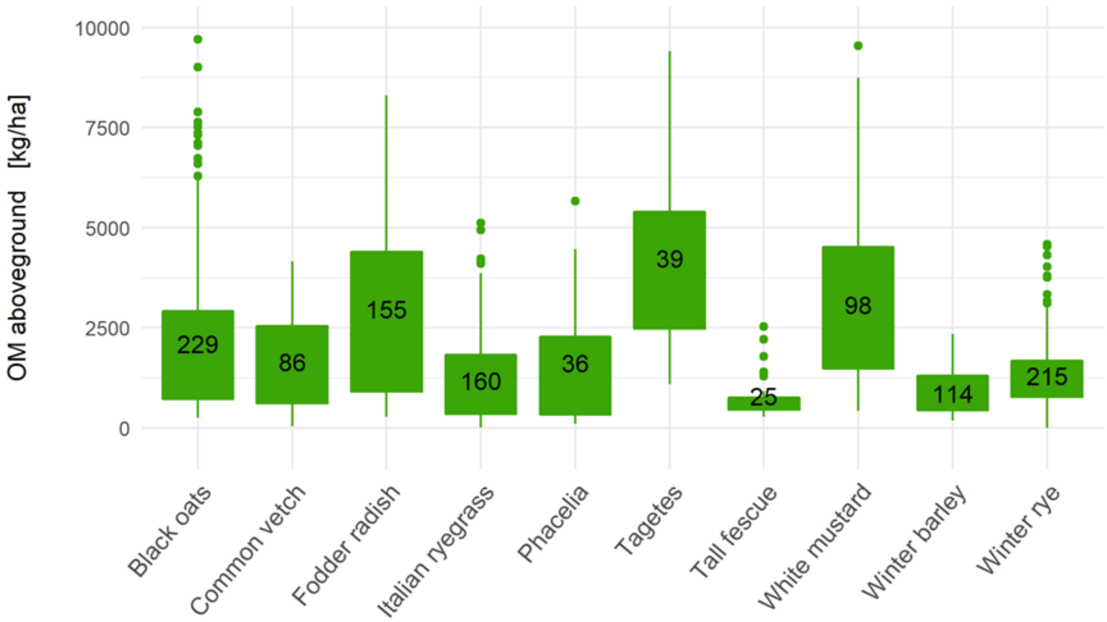

Figure 2. The spread of the data of the aboveground OM production for all species. The number indicates the number of data entries.

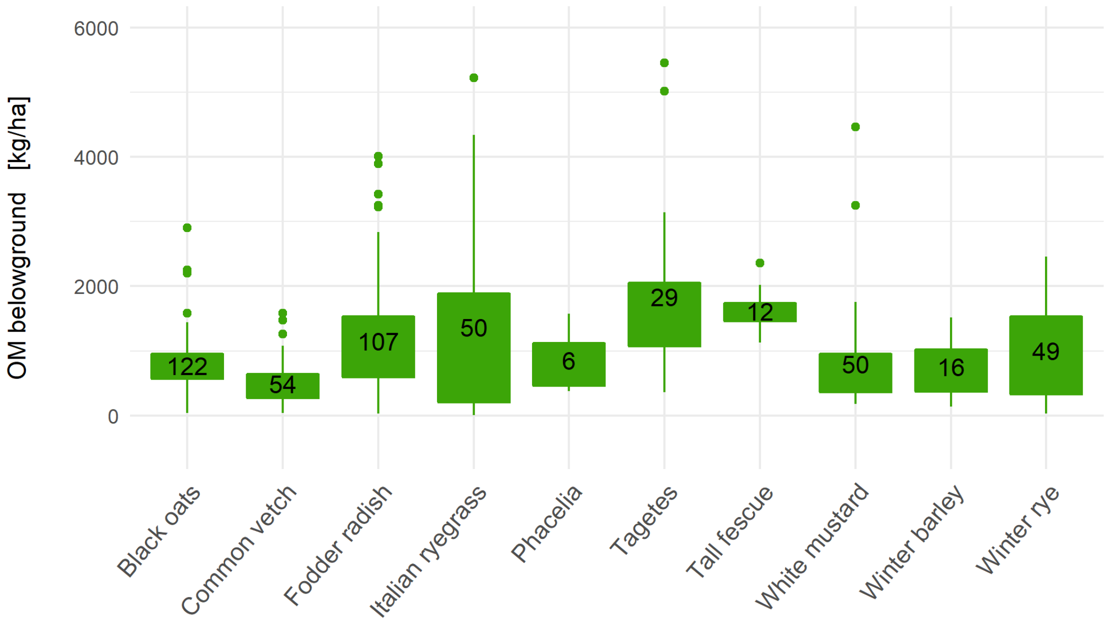

Figure 3. The spread of the data of the belowground OM production for all species. The number indicates the number of data entries.

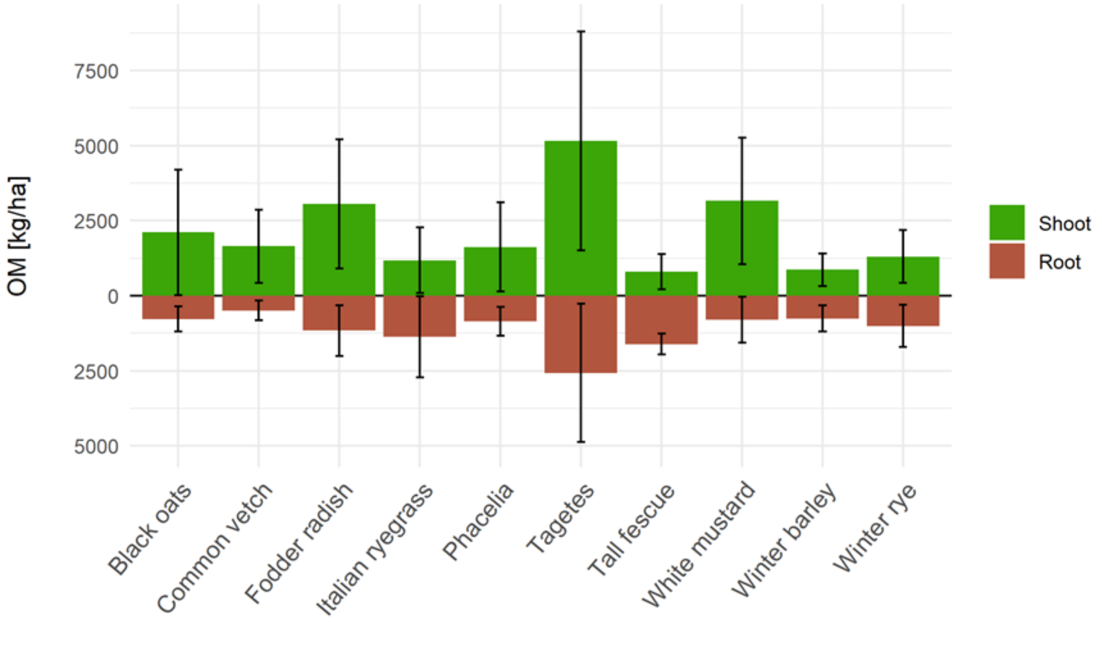

Figure 4. The average and standard deviation per cover crop species for shoot and root OM in kg per ha.

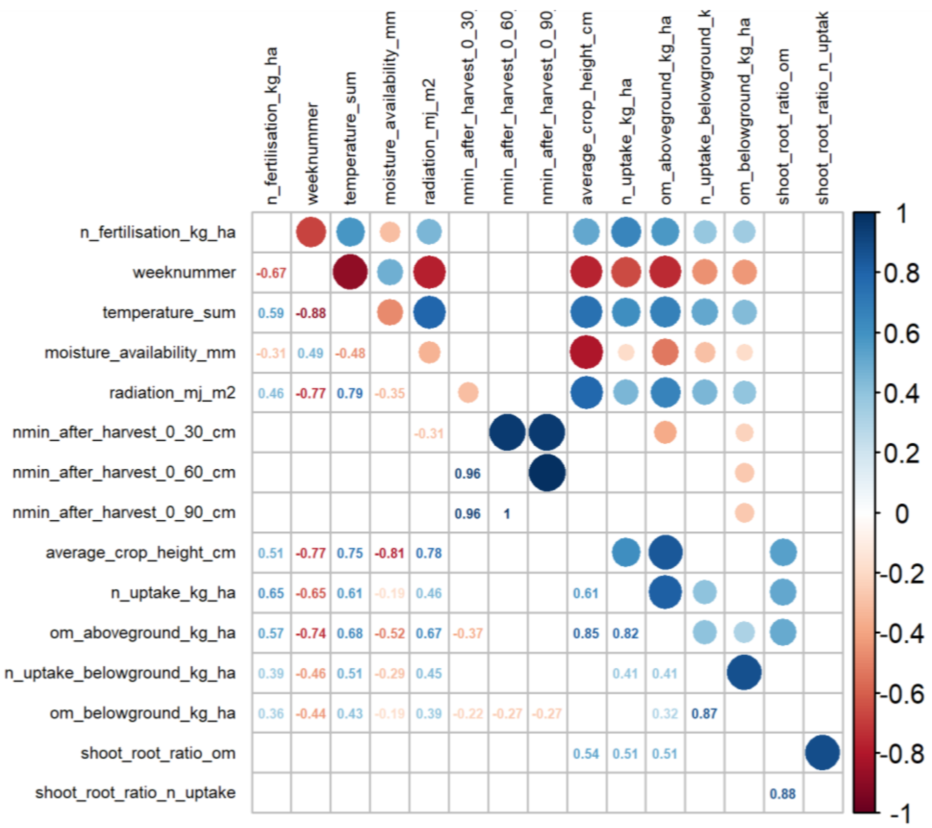

Figure 5. Correlation table for numerical variables. Blue dots stand for a significant positive correlation and red dots for a significant negative correlation. The size of the dot indicates the strength of the correlation. The correlation coefficient per significant correlation is available in the left diagonal part of the graph.

Figure 5 shows the correlations between numerical variables. A strong negative relationship was found between sowing week number and temperature sum (-0.88) and radiation (-0.77), while the relationship with moisture availability was positive (+0.49). Moisture availability was negatively correlated with height (-0.81) and aboveground OM (-0.52). Temperature sum correlates strongly with radiation (+0.79). Week number has a strong negative correlation with the plant growth variables while temperature sum and radiation have strong positive correlations. N fertilization has a positive correlation with the plant growth variables while soil mineral N is only weakly positively correlated with growth variables.

The categorical variables also have interactions. There is an interaction between species and soil type as some species are preferred for different soil types (Figure 7. The number of observations of each species per soil type. Including literature data.). Furthermore, an interaction is present between species and pre-crop, explainable by soil quality concerns and harvest times (Figure 6. The number of observations per crop and pre-crop combination. Including literature data.). This also entails that sowing time has an interaction with species. Furthermore, there is an interaction between N fertilization and species, due to differing fertilization demands and an interaction between N fertilization and sowing time, explainable since after week 40 no fertilization is allowed (-0.67).

3.2.2 Explanatory factors

The model output of the results is available in paragraph 7.4. The best explanatory factor for aboveground biomass and aboveground N uptake, after crop species (OM: n=1138, R^2=0.21, N: n=895, R^2=0.23), was crop height (OM: n=498, R^2=0.69, N: n=422, R^2=0.50), followed by sowing week number (OM: n=1134, R^2=0.57, N: n=895, R^2=0.47:). Sowing week was a better predictor than radiation (OM: n=1036, R^2=0.49, N: n=865, R^2=0.34) and temperature sum (OM: n=1036, R^2=0.45, N: n=865, R^2=0.44). Because of this, the choice was made to go further with sowing week number and crop height as a second priority, since the number of observations is smaller for crop height. Soil type significantly improved the model with week number when analysing all crops together (OM: n=1133, R^2=0.60) but the spread of the data for different sowing weeks was not even when looking at the species separately (paragraph 7.5). Because of this, soil type was excluded from the model. Nitrogen fertilization gave a significant improvement of the model across all species (n=1058, R^2=0.66). However, it was not used as a factor for the species separately as there were not multiple fertilization levels available with a good spread over different sowing weeks (Table 23. The number of observations for different fertilisation levels kg N/ha. In grey the crops for which several fertilization levels are included. Including literature data.). Moisture availability was overall significant on OM aboveground (n=1036, R^2=0.59) but only significant for some species when looked at separately. However, the effect of moisture availability on kg OM per ha was negligible for our intended use as reference values (i.e. the influence on OM per 50 mm of moisture was too small to motivate different reference values). Moisture availability was therefore not included as a factor in the model. Based on these results the choice was made to only use sowing week number and crop height as explanatory variables for aboveground OM production and N uptake.

The best explanatory factors for shoot:root OM ratio and shoot:root N uptake ratio, after crop species (OM: n=411, R^2=0.32, N: n=191, R^2=0.54) were aboveground OM production (n=411, R^2=0.48) and aboveground N uptake (n=191, R^2=0.57), respectively. As no additional variables were selected for the response variable aboveground OM, we also didn't use any additional variables for aboveground N uptake and the two ratio variables.

3.2.3 Model selection - Organic matter

Graphs for all response variables per species are available in the appendix where also graphs for comparison with literature data is available for aboveground OM and belowground OM (paragraphs 7.5 - 7.10). In paragraph 7.11 figures of belowground biomass plotted against sowing week number are available. Table 11 and Table 12 summarize the model performances per species. A model for the relation between crop height and aboveground OM or N uptake was only fit for some species.

Table 11. Quantitative and qualitative summary of prediction model performance. The goodness of prediction is based on the adjusted R^2, visual assessment and the amount and type of available data. It is expressed either as poor, average or good. Recommendations and considerations per species are provided in the remarks.

Crop	# data entries	Adjusted R2	Goodness of prediction	Remarks
Winter rye	188	OM aboveground: R^2 = 0.29, see 7.5.1 Shoot:root ratio: R^2=0.75, see 7.6.1	Due to the large number of measurements the accuracy of the reference values is **average**	• Majority of data from a sandy soil • The large variation per sowing week, resulted in poor model fit • Risk for overestimation of belowground biomass for OM aboveground of more than 2250 kg/ha • It is recommended to gather more data of winter rye before week 35 from a sandy soil and from clay and reclaimed peat soil for all sowing times
Black oats	225 Crop height: 134	OM aboveground: R^2= 0.82, see 7.5.2 Shoot:root ratio: R^2=0.70, see 7.6.2 Crop height: R^2=0.83, see 7.7.2	Due to the large number of measurements and the good model fit the accuracy of the reference values is **good**	• Majority of data from a sandy soil • Risk for overestimation of belowground biomass for OM aboveground of more than 8000 kg/ha
Common vetch	74 Crop height: 36	OM aboveground: R^2=0.43, see 7.5.3 Shoot:root ratio: R^2=0.46, see 7.6.3 Crop height: R^2=0.54, see 7.7.3	Due to the average number of measurements and the average model fit the accuracy of the reference values is **average**	It is recommended to gather more data
Fodder radish	141 Crop height: 75	OM aboveground: R^2=0.79, see 7.5.4 Shoot:root ratio: horizontal line, see 7.6.4 Crop height: R^2=0.79, see 7.7.4	Due to the large number of measurements and the good model fit the accuracy of the reference values is **good**	• The height data is visually distributed in three different clouds or areas • It is recommended to gather more height data
Italian ryegrass	117	OM aboveground: R^2=0.60, see 7.5.5 Shoot:root ratio: horizontal line, see 7.6.5	Due to the large number of measurements and the average model fit the accuracy of the reference values is **average**	• There were no significant differences between the model prediction of the Italian ryegrass sown after the main crop and the data of the undersown Italian ryegrass (see 7.5.4) • The data was mainly from clay and reclaimed peat soil in weeks <37 and from a sandy soil from week 37 and above • It is recommended to gather more data
Phacelia	32	OM aboveground: R^2=0.93, see 7.5.6 Shoot:root ratio: average, see 7.6.4 Crop height: R^2=0.88, see 7.7.6	Due to the low number of datapoints and the good model fit, the accuracy of the reference values is **average**	It is recommended to gather more data, especially belowground data
Tall fescue	24	OM aboveground: horizontal line, see 7.5.7 Shoot:root ratio: average, see 7.6.7	Due to the low number of datapoints from different conditions the accuracy of the reference value is **poor**	• Data was from only two sowing dates on sand and had a large variation • It is recommended to gather more data, especially belowground data
White mustard	90 Crop height: 55	OM aboveground: R^2=0.74, see 7.5.8 Shoot:root ratio: horizontal line, see 7.6.8 Crop height: R^2=0.86, see 7.7.8	Due to the large number of datapoints and the good model fit the accuracy of the reference values is **good**	• The crop height the data was visually distributed in three different clouds or areas • It is recommended to gather more height data
Winter barley	111	OM aboveground: horizontal line until week 39, averages for week 40 and 42 see 7.5.9	Because no model could be fit and the large variation, the accuracy of the reference values is **poor**	• Data had a large spread per sowing week number, with a visual decrease at later sowing times

		Shoot:root ratio: average, see 7.6.9		• It is recommended to gather more data
Tagetes	45 Crop height:30	OM aboveground: R^2=0.54. see 7.5.10 Shoot:root ratio: R^2=0.44, see 7.6.10 Crop height: R^2=0.73, see 7.7.10	• Sowing time: Due to the average model fit and low amount of data the accuracy of the reference values is **average** • Crop height: Due to the average number of datapoints and the good model fit the accuracy of the reference values is **good**	• It is recommended to gather more data • Shoot:root ratio when OM aboveground is higher than 10000 kg/ha has very few data points and is therefore uncertain

3.2.4 Model selection - Nitrogen uptake

Table 12. Quantitative and qualitative evaluation of prediction model performance. The goodness of prediction is based on the adjusted R^2, visual assessment and the amount and type of available data. It is expressed either as poor, average or good. Recommendations per species are provided in the remarks.

Crop	# data entries	Adjusted R2	Goodness of prediction	Remarks
Winter rye	188	N uptake aboveground: R^2=0.41, see 7.8.1 Shoot:root ratio: R^2=0.35, see 7.9.1	Due to the poor model fit, low number of datapoints from different conditions the accuracy of the reference values is **average**	See remarks in table 11
Black oats	174	N uptake aboveground: R^2=0.44, see 7.8.2 Shoot:root ratio: average, see 7.9.2 Crop height: R^2=0.47, see 7.10.2	• Sowing time: Due to the poor fit the accuracy of the reference value is **average** • Crop height: Due to the large number of datapoints and the average model fit the accuracy of the reference values is **average**	Visually the model fit to the height data was poor with scattered data and a large cloud
Common vetch	54	N uptake aboveground: R^2=0.34, see 7.8.3 Shoot:root ratio: average, see 7.9.3 Crop height: R^2=0.68, see 7.10.3	• Sowing time: Due to the visual model fit the reference value is **average** Crop height: Due to the low number of datapoints and the average model fit the accuracy of the reference values is **average**	More data is needed of belowground N uptake
Fodder radish	91	N uptake aboveground: R^2=0.49, see 7.8.4 Shoot:root ratio: horizontal line, see 7.9.4 Crop height: R^2=0.90, see 7.10.4	• Sowing time: Due to the large number of datapoints the accuracy of the reference value is **average** • Crop height: Due to the average number of datapoints and the high model fit the accuracy of the reference values is **poor**	• The data has a large variation, especially with early sowing • The height data contains two clouds from two different soil types, with a lack of data for the crop heights in between • It is recommended to gather more data to get a better prediction
Italian ryegrass	117	N uptake aboveground: R^2=0.51, see 7.8.5 Shoot:root ratio: average, see 7.9.5	Due to the large number of datapoints from different conditions the accuracy of the reference value is **poor**	• It is recommended to gather more data, especially from weeks 28-36, to get a better prediction • The shoot:root N uptake ratio has a large variation and few data points
Phacelia	30	N uptake aboveground: R^2=0.66, see 7.8.6 Shoot:root ratio: average, see 7.9.6 Crop height: R^2=0.73, see 7.10.6	• Sowing time: Due to the low number of datapoints and the good model fit the accuracy of the reference value is **average**	• The shoot:root N uptake ratio has a large variation and few data points • The height data has a large variation and is poorly spread over the soil types

			• Crop height: Due to the low number of datapoints and the good model fit the accuracy of the reference values is **poor**	• It is recommended to gather more data to get a better prediction.
Tall fescue	24	N uptake aboveground: horizontal line, see 7.8.7 Shoot:root ratio: R^2=0.44, see 7.9.7	Due to the low number of datapoints, lack of data from different conditions and missing a suitable model, the accuracy of the reference value is **poor**	• The shoot:root N uptake ratio was never determined for OM aboveground higher than 15 kg/ha and the value for belowground in therefore an extrapolation • It is highly recommended to gather more data to get a better prediction.
White mustard	67	N uptake aboveground: R^2=0.22, see 7.8.8 Shoot:root ratio: horizontal line, see 7.9.8	Due to the poor model fit the and low number of observations, the accuracy of the reference value is **poor**	• The data shows a large variation • It is recommended to gather more data to get a better prediction
Winter barley	111	N uptake aboveground: a horizontal line was fit between week 35 and 39, averages for week 40 and 42, see 7.8.9 Shoot:root ratio: average, see 7.9.9	Due to the fact that no model could be fit despite the high number of data points, the accuracy of the reference values is **poor**	• The data shows a large variation • All data comes from a sandy soil • It is recommended to gather more data from different soil types and sowing times to get a better prediction
Tagetes	18	N uptake aboveground: average, see 7.8.10 Shoot:root ratio: R^2=0.40, see 7.9.10	Due to that no model could be fit and the low number of datapoints the accuracy of the reference values is **poor**	• The data has a large variation • It is recommended to gather more data from more different sowing times to get a better prediction

3.3 Reference value tables

Following the steps as described in 2.3.2 a number of reference value tables were produced. Tables are provided for different sowing dates from 15 July to 15 October of OM (Table 13) as well as EOM (Table 14), both given in kg/ha. Additionally, tables are provided for different crop heights from 10 to 150 cm of OM (Table 15) as well as EOM (

Table 16).

Table 13 . The reference values based on sowing time in kg OM per ha predicted by the models.

	Sowing time						
Crop	**15-Jul**	**01-Aug**	**15-Aug**	**01-Sep**	**15-Sep**	**01-Oct**	**15-Oct**
Winter rye	3150					2400	1400
Black oats	-	7600	4450	2250	1650	1450	1200
Common vetch	3700	3100	2200	1550	950	-	-
Fodder radish	9000	6900	4250	2800	1550	600	-
Italian ryegrass	7050	6100	4650	3700	2750	1800	850
Phacelia	-	4650	2550	1500	750	300	-
Tall fescue	-	-	-	-	3350		-
White mustard	8100	5700	3350	2350	1650	1150	-
Winter barley	-	-	-	2300			1300
Tagetes	11700	5700	4500	-	-	-	-

Table 14. The reference values based on sowing time in kg EOM per ha predicted by the models.

	Sowing time						
Crop	**15-Jul**	**01-Aug**	**15-Aug**	**01-Sep**	**15-Sep**	**01-Oct**	**15-Oct**
Winter rye	800					650	400
Black oats	-	1650	1000	550	400	350	300
Common vetch	800	700	500	350	250	-	-
Fodder radish	2050	1600	950	650	350	150	-
Italian ryegrass	1850	1600	1250	1000	750	450	200
Phacelia	-	1100	600	350	150	50	-
Tall fescue	-	-	-	-	1050		-
White mustard	1800	1250	750	500	350	250	-
Winter barley	-	-	-	650			300
Tagetes	2500	1350	1200	-	-	-	-

Table 15 . The reference values based on crop height in kg OM per ha predicted by the models.

	Crop height (cm)														
Crop	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Black oats	-	-	-	2000	2400	2800	3250	3800	4350	4900	5550	6250	6950	7750	8550
Common vetch	-	1000	2050	2500	-	-	-	-	-	-	-	-	-	-	-
Fodder radish	350	1100	1800	2450	3150	3750	4400	4950	5500	6050	6550	7050	7500	7950	8350
Phacelia	-	550	1250	1950	2550	3050	3500	3900	4250	-	-	-	-	-	-
White mustard	750	850	1000	1150	1300	1500	1700	1950	2200	2500	2900	3300	3750	4300	4900
Tagetes	-	-	-	-	-	-	4550	4800	5300	5900	6650	7550	8700	10000	11750

Table 16. The reference values based on crop height in kg EOM per ha predicted by the models.

	Crop height (cm)														
Crop	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**	**150**
Black oats	-	-	-	500	600	650	750	850	1000	1100	1250	1400	1500	1700	1850
Common vetch	-	250	450	550	-	-	-	-	-	-	-	-	-	-	-
Fodder radish	100	250	400	550	700	850	1000	1150	1250	1400	1500	1600	1700	1800	1900
Phacelia	-	150	300	450	600	700	800	900	1000	-	-	-	-	-	-
White mustard	150	200	200	250	300	350	400	450	500	550	650	750	850	950	1100
Tagetes	-	-	-	-	-	-	1150	1200	1250	1350	1500	1650	1900	2150	2500

For nitrogen uptake, one table is provided based on sowing time (Table 17) and one for crop height (Table 18), both in kg N/ha.

Table 17. The reference values based on sowing time in kg N per ha predicted by the models.

	Sowing time						
Crop	**15-Jul**	**01-Aug**	**15-Aug**	**01-Sep**	**15-Sep**	**01-Oct**	**15-Oct**
Winter rye	-	-	-	-	75	55	40
Black oats	-	115	75	45	40	35	25
Common vetch	-	-	-	-	95	-	-
Fodder radish	240	175	110	80	55	40	-
Italian ryegrass	-	-	-	-	-	40	-
Phacelia	-	90	50	40	30	20	-
Tall fescue	-	-	-	-	40		-
White mustard	145	120	95	80	65	55	-
Winter barley	-	-	-	40			20
Tagetes	125			-	-	-	-

Table 18. The reference values based on crop height in kg N per ha predicted by the models

	Crop height (cm)									
Crop	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Black oats	20	35	45	55	60	70	75	80	80	85
Common vetch	-	65	-	-	-	-	-	-	-	-
Fodder radish	25	35	45	55	75	100	125	165	215	280
Phacelia	-	25	40	55	70	85	90	90	90	-

4 Discussion

4.1 Humification coefficients

Due to the large variation in the HC data and the low number of repetitions, HC values specific for a crop species cannot be reliably defined from this experiment. In order to derive a stable average value across species or for a single species, as well as for shoot and root separately, multiple times more repetitions are required using this methodology. However, we can tentatively conclude that the average HC for belowground biomass does not differ from the current reference value of 0.35 whereas the HC for aboveground biomass is found to be significantly higher than 0.2. In this experiment, the difference in HC between aboveground and belowground biomass is smaller than the difference between the current reference values of the two, with shoot biomass having an HC closer to the value for root biomass. Several literature sources do however conclude that roots have slower decomposition than shoots (Shahbaz, 2016 ; Katterer et al., 2011) We also found that less developed plant matter had a statistically significant higher HC than more developed material, especially to be seen in roots. This is contradictory to our expectations as lignin contents are higher in older plant material, which makes it more recalcitrant to decomposition (Stewart et al., 2015). However, in this experiment also the more developed plant material was not yet lignified (before flowering stage). No alternative explanation is at hand for this result other than that it is an artefact of the large variation in measurements. Regarding the development stage, we tentatively conclude that there is no support for using different HC values for different growth stages of these cover crops.

Other factors also influence the reliability of the derived HC's with this methodology. The experiment was only performed with sandy soil. However, previous experiments show that soil type can have an influence on the rate of decomposition, with a higher rate (lower HC) with a sandy soil than on clay soil (van der Burgt et al., 2011), which makes it unwarranted to use the same values for all soil types without further investigation of this effect. This previous finding is corroborated by studies showing that clay minerals protect carbon, especially at low residue addition rates, and that this effect is dependent on the porous structure and surface area of the clay minerals (Singh et al., 2019). Another study shows an interaction between soil type and the type of organic matter added, with varying effects on the decomposition rate (Mewes, 2017). In literature, other influences on decomposition can be found such as higher decomposition rates with more crops in the rotation due to higher microbial activity (McDaniel et al., 2014). Additionally, the amount of organic matter input can have a large effect on the decomposition speed, due to influences of physical protection and priming effects that differ between above- and belowground biomass (Shahbaz et al., 2016). However, there are also studies showing that amount does not have an influence on the measured HC using this method (Rietra et al., in press). In the literature of the last 20-30 years few papers are available on HC values. One study on inundated soils in China (not temperate climate) shows an HC of 0.31 for cereal stubble and 0.32 for roots (Sparks, 2004). A higher HC is expected on inundated soil than on dryland. These values are similar to the current reference values for straw and root material. Another study on a silty loam in Missouri (temperate climate) finds HC's of 0.2 for wheat stubble and 0.24 for roots (Paul et al., 1996).

It is also possible that a correction factor is needed to translate the HC value to an HC value under field conditions. Under field conditions the temperature and moisture levels are variable, and the soil and plant matter are not dried, mixed, sieved or ground into small pieces as is done in the incubation experiments. Based on this, it is possible that both higher and lower HC values would occur under field conditions. The incubation measurements do however give an impression of the relative speed of decomposition for the different materials in relation to each other. However, also on this aspect, we do not see any trends in the HC values that we are able to explain by either lignin or nitrogen content of the material (Stewart et al., 2015). To attempt to translate the HC values to field conditions we transformed the values based on the current reference value for straw. The derived HC's of the references straw and English ryegrass were 0.4 and 0.29 respectively in our experiment. However, the current HC reference value for straw is 0.3, which was determined in old field experiments. If we assume that the current reference value is valid for field conditions based on old experiments, we can transform all the HC's by multiplying with (0.3/0.4=) 0.747 (Table 19. HC coefficients of cover crops after multiplication by the straw reference factor of 0.747.) This makes HC values for aboveground biomass more similar to the current HC reference value, while for roots it makes it lower than the current reference values. A possible explanation for the low value for roots is that the cover crops were still relatively young plants (pre-flowering phase) and that 0.35 is only reached in older, more lignified plants. Without validation by means of new field experiments we cannot conclude if this transformation gives more accurate HC values than the measured values.

Table 19. HC coefficients of cover crops after multiplication by the straw reference factor of 0.747.

Plant part	Cover crop	Average HC
Shoot	White mustard	0.28
	Fodder radish	0.21
	Common vetch	0.18
	Black oats	0.27
	Tagetes	0.24
	Mixture-3	0.25
	Mixture-12	0.24
	Average	**0.22**
Root	White mustard	0.31
	Fodder radish	0.20
	Common vetch	0.18
	Black oats	0.30
	Tagetes	0.27
	Mixture-3	0.25
	Mixture-12	0.26
	Average	**0.25**

The large variation makes us unable to reliably determine new HC reference values. A similarly large variation is also found in other studies where the same methodology is applied (Rietra et al., 2019). Due to the lack of alternatives and the fact that the derived HC values are not largely different from current reference values (within 0.15 difference), we choose to use the current HC reference values for determining the EOM reference values in this report. As a conclusion, we do not advise to change the current HC reference values based on our experiments, instead we recommend more extended research.

4.2 Organic matter and nitrogen uptake

The spread of the OM data was large and there were many influencing factors that were also correlated, complicating independent analysis of their effects. However, this is to be expected when using a non-experimental but a compiled, heterogenous dataset. Soil type had a significant effect, but with this dataset we were unable to, to determine if there were significant differences in biomass production for different sowing weeks. Regarding moisture, it was expected that moisture availability could have a large influence on early growing stages, however by using a moisture balance over the whole growing period, this is aspect is not properly accounted for in the dataset. Hence there is no positive effect of moisture availability on the cover crop, but a negative one instead, probably due to the trade-off with radiation. The dataset also contained data on N fertilization and mineral N in the soil, however due to many missing values it was not possible to include these as factors in the further analysis as it would greatly decrease the size of the dataset for the models.

The reliability of the predictions varies per species due to the number of data entries and the spread of data over different growing situations (e.g. years and soil types). For some species and growing situations, it is advised to gather more data to be able to provide better predictions (see 3.2.3 and 3.2.4). In general, the crop height dataset is smaller than the OM aboveground dataset and also based on more recent measurements. The tables based on sowing time are therefore backed by more data and may therefore be more accurate.

When comparing the new reference values with the current ones we see that the predictions for all species, except for tagetes, are similar to the previous reference values when considering the sowing month of early to late August. The old reference values were all based on data from cover crops sown before September 1st, which validates our dataset.

5 Conclusions

In this study we attempted to update the HC's for above- and belowground biomass of cover crops. We also gathered data and compiled a large dataset of cover crop biomass and nutrient content. With the data we used model calculation to determine new reference values for the EOM production and N uptake of cover crop species, for different sowing times and crop heights. The main conclusions and findings that also responds to the research questions are summarized as following:

- Due to the large variation in the data from the incubation experiments, no reliable distinction could be made for HC's between plant part, species or for different development stages. We concluded to not use these new values for calculating EOM values.
- As continuation of the research on HC, similar experiments with a much larger number of repetitions is recommended, or, another approach and methodology altogether. If HC's are determined in non-field conditions, validation experiments are recommended in order to determine a correction factor. For both steps, experiments on different soil types with varying amount of additions are advised.
- We also recommend the development of a standard protocol for determining the humification coefficients of organic material in respiration experiments, since studies use slightly different methodology which may influence the results.
- Sowing week number and crop height are good predictors for aboveground OM production and N uptake of cover crops. Additional variables (moisture availability, soil type, N fertilization) do have a significant effect statistically but there was too little data available in order to determine the size of the effects due to interactions and a lack of spread in the data over the sowing weeks.
- The predictions for EOM of all species except for tagetes are similar to the current reference values when considering the sowing month of early to late August. This validates the dataset as the current reference values were based on data from cover crops sown before September 1st.
- The reference values for N uptake are less reliable than the ones for aboveground EOM due to a smaller dataset and generally worse performing models. The interpretation of the reference values should be done critically.
- The model fit of the predictions is poor for some species and response variables, however this fit may improve if more data is gathered. It is recommended to gather more data on winter rye, common vetch, Italian ryegrass, phacelia, tall fescue, winter barley and tagetes. This is especially needed for the N uptake predictions.
- In order to establish new reference values for species that were not included in this analysis, more data has to be gathered. These crops include English ryegrass, camelina, grass-clover, hairy vetch, Niger, oats and red clover.

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7 Appendices

7.1 Incubation experiment

Table 20. The sowing data and growing days of the incubated cover crop species for determination of humification coefficients.

Species	Growth stage 1 (less developed)		Growth stage 2 (more developed)	
	Sowing date	Growing days	Sowing date	Growing days
Fodder radish	23rd of August	52	23rd of august	100
Black oats				
Common vetch				
Fodder radish, black oats, common vetch				
SolaRigol				
Tagetes	14th of August	63	8 June	131
White mustard	5th of August	76	5th of September	107

,

gg ggg 21. Allocation of the crop material over the incubation series.

Cover crop species	Development	Series
White mustard	Less developed	1
	More developed	1
Fodder radish	Less developed	2
	More developed	1
Common vetch	More developed	2
	More developed	1
Black oats	Less developed	2
	More developed	1
Mixture-3	Less developed	2
	More developed	1
Mixture-12	Less developed	2
	More developed	1
Tagetes	Less developed	2
	More developed	2
English ryegrass	-	1
Wheat straw	-	1

7.2 Data sources

Table 22. An overview of the data sources.

Reference	Crop	Country	Year of experiment	Soil type	Pre-crop	Type
Literature data						
Allison et al., 1998	Fodder radish, white mustard, winter rye, phacelia	UK	1998	Loam	-	After main crop
Buechi et al., 201	common vetch	CH	2011	loam	Winter wheat	After main crop
Cougnon et al., 2015	Winter rye, Italian ryegrass	BL	2013	Loam	Corn	After main crop
De Ruijter, 2012	fodder radish	NL	n.a.	sandy	Triticale	After main crop
Grosse and Hess, 2015	common vetch, yellow mustard	DE	2011-2012	loam	winter wheat	After main crop
Hui et al., 2018	spring barley, winter wheat	DK	n.a.	loamy sand	n.a.	After main crop
Kolbe et al., 2004	phacelia, yellow mustard	DE	n.a.	loam	-	After main crop
Li et al., 2015 cited by Hu et al., 2018	fodder radish, Italian ryegrass	DK		loamy sand	Cereal	After main crop
Moeller and Reents, 2009	common vetch, fodder radish, hairy vetch	DE	n.a.	loam	Peas	After main crop
Mueller et al., 2001	hairy vetch, common vetch, winter rye, Italian ryegrass	DK	n.a.	sandy loam	Barley (straw incorporated)	After main crop
Mutegi et al., 2011 cited by Hu et al., 2018	fodder radish	DK	n.a.	loamy sand	Cereal	After main crop
Thorup-Kristensen et al., 2001	phacelia, hairy vetch, winter rye, fodder radish, oat, Italian ryegrass	DK	n.a.	sandy loam	Pea	After main crop
Thorup-Kristensen, 1994	fodder radish, phacelia, yellow mustard, hairy vetch, winter rye	DK	1992	sand	Brussels sprouts	After main crop
Hu et al., (2018) Cited by author, Unpublished raw data.	fodder radish	DK	n.a.	n.a.	Cereal	After main crop
Wendling et al., 2016	Black oat, common vetch, fodder radish, phacelia, white mustard	CH	2011	loam	alfalfa	After main crop
Compiled data						

Schroder et al., 1992	Italian ryegrass, winter rye	NL	1988-1990	Sand	Corn	Undersowing, After main crop
Van Dijk et al., 1997	Italian ryegrass, winter rye	NL	1991-1994	Sand	Corn	Undersowing, After main crop
Hoek et al., 2006	Fodder radish, white mustard, Italian ryegrass, winter rye and common vetch	NL	2004-2005	Clay, peat-type	Zomergerst, zwarte braak, winterkarwij, zetmeelaardappelen, braak	After main crop
Van Geel et al., 2012	Fodder radish, winter rye	NL	2010	Sand	Triticale	After main crop
Van Geel & Verstegen, 2008	Winter rye, winter barley	NL	2007	Sand	Green bean	After main crop
Haagsma et al. (2020), Groenbemesterproef 2015-2017. Unpublished raw data.	Black oats, common vetch, English ryegrass, phacelia, white mustard, spring barley, niger, red clover, grass clover, mixtures	NL	2015-2017	Sand, clay	Potato, peas, spelt, spring wheat, spring barley, green bean pumpkin	After main crop
Porre et al. (2019), Clever cover cropping Unpublished raw data.	Fodder radish, black oats, common vetch, mixtures	NL	2016-2019	Sand	Winter wheat, corn, potato, Barley	After main crop
Van Geel (2020) Vanggewassen mais en aardappelen. Unpublished raw data.	Winter barley, black oats, winter rye, tall fescue, Italian ryegrass	NL	2018-2019	Sand	Potato, corn	After main crop, undersowing, sown with main crop
Selin-Noren (2020) Unpublished raw data.	Fodder radish, black oats, winter barley, common vetch, white mustard, tagetes, mixtures	NL	2019	Sand, peaty-soil, clay	Spring barley, green bean, onion, zucchini, Italian ryegrass, English, ryegrass, pumpkin sugar beet, maize, spring wheat, winter barley,	After main crop, undersowing, sown with main crop
Van der Vegt (2018) Unpublished raw data.	Black oats, fodder radish, white mustard, tagetes, mixtures	NL	2018	Sand	n.a.	After main crop
Harms (2020) Unpublished raw data.	English ryegrass, black oats, tagetes, fodder radish	NL	2011-2016	Sand	Peas, spring barley, potato	After main crop
Dekkers (2020) Unpublished raw data.	Black oats, fodder radish, white radish, mixtures,	NL	2019	Clay	Onion, winter barley, spring wheat, spinach, garlic	After main crop

7.3 Data descriptives

Table 23. The number of observations for different fertilisation levels kg N/ha. In grey the crops for which several fertilization levels are included. Including literature data.

Kg N/ha	0	27	30	44	50	54	60	65	68	80-133
Winter_rye	151	12			17				12	
Black_oats	17		2	4	3	4	4	16		4
Common_vetch	34		2		19	4		1		
Fodder_radish	53		2	4	31	16		16		5
Italian_ryegrass	96				25					
Phacelia	26			3	2	4				
Tagetes	8				6	4	5	18		4
Tall_fescue	24									
White_mustard	37			4	28	4		16		4
Winter_barley	111									

Figure 6. The number of observations per crop and pre-crop combination. Including literature data.

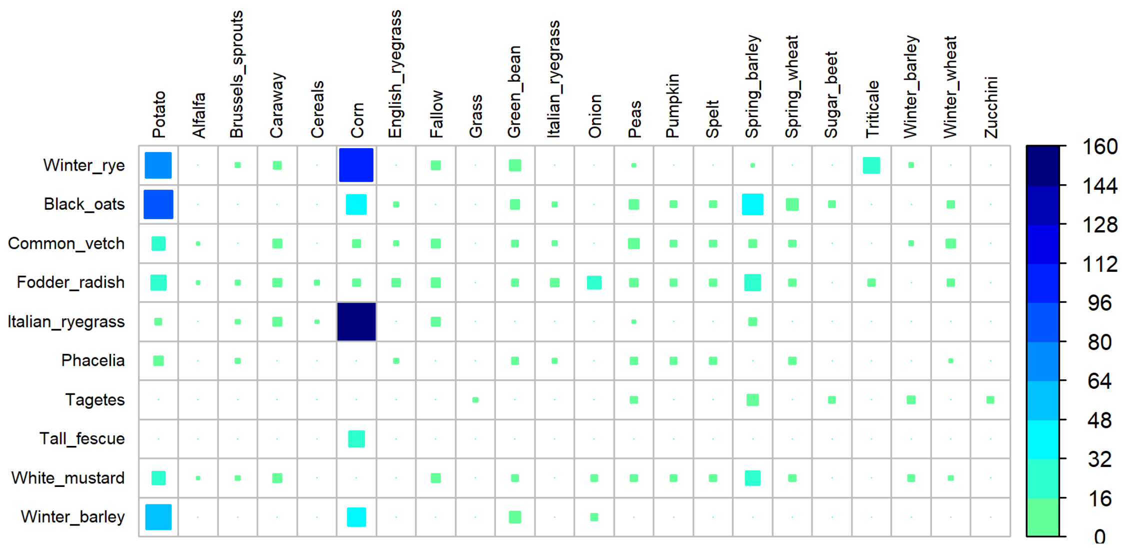


Figure 7. The number of observations of each species per soil type. Including literature data.

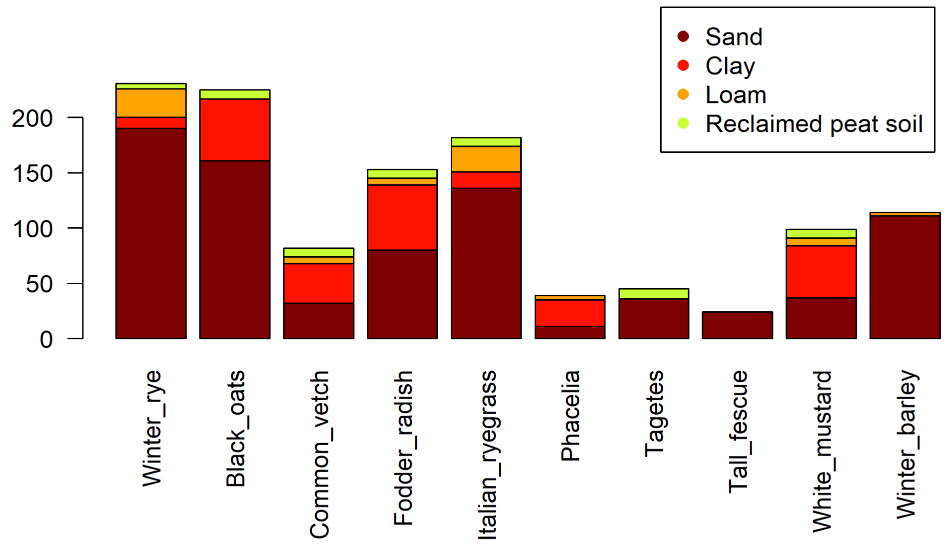


Table 24. The number of observations of each species. Excluding literature data.

Crop	Entries per crop	nmin _0_30_cm	nmin _0_60_cm	nmin _0_90_cm	average_crop_height	n_uptake_above	om_aboveground	n_uptake_belowground	om_belowground	shoot_root_ratio_om	shoot_root_ratio_n_uptake
Black oats	225	88	87	87	134	174	225	78	118	107	72
Common vetch	74	5	5	5	36	54	74	4	49	45	4
Fodder radish	141	12	12	12	75	91	141	40	99	96	38
Italian ryegrass	117	25	25	25	23	117	117	5	28	28	5
Phacelia	32	8	8	8	32	30	32	4	4	4	4
Tagetes	45	0	0	0	30	18	43	19	33	31	18
Tall fescue	24	0	0	0	24	24	24	12	12	12	12
White mustard	90	8	8	8	55	67	90	15	49	44	15
Winter barley	111	90	90	90	51	111	111	16	16	16	16
Winter rye	188	116	116	116	48	188	188	12	27	27	12

7.4 Factor analysis

7.4.1 Models for OM aboveground

Only crop

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.8301 -0.5693  0.0913  0.6842  2.0786

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            6.830077   0.067319 101.458  < 2e-16 ***
CropBlack_oats         0.397632   0.093604   4.248 2.33e-05 ***
CropCommon_vetch       0.085136   0.127036   0.670 0.502880
CropFodder_radish      0.861411   0.103693   8.307 2.76e-16 ***
CropItalian_ryegrass -0.368505   0.102191  -3.606 0.000324 ***
CropPhacelia         -0.005159   0.175977  -0.029 0.976619
CropTagetes           1.517953   0.163293   9.296  < 2e-16 ***
CropTall_fescue      -0.323468   0.210205  -1.539 0.124126
CropWhite_mustard     0.989746   0.118933   8.322 2.46e-16 ***
CropWinter_barley    -0.278582   0.113491  -2.455 0.014251 *

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9756 on 1137 degrees of freedom
  (48 observations deleted due to missingness)
Multiple R-squared:  0.2196, Adjusted R-squared:  0.2134
F-statistic: 35.54 on 9 and 1137 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
            Sum Sq   Df  F value    Pr(>F)
(Intercept) 9796.5    1 10293.66 < 2.2e-16 ***
Crop        304.4     9    35.54 < 2.2e-16 ***
Residuals   1082.1 1137

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + temperature

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + temperature_sum,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.7520 -0.4317  0.0494  0.4665  2.4971

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            6.077e+00  6.769e-02  89.780  < 2e-16 ***
CropBlack_oats         1.274e-01  7.353e-02   1.733 0.083457 .
CropCommon_vetch      -4.697e-01  1.028e-01  -4.567 5.54e-06 ***
CropFodder_radish      3.030e-01  8.493e-02   3.567 0.000377 ***
CropItalian_ryegrass -2.385e-01  8.767e-02  -2.720 0.006632 **
CropPhacelia          -5.697e-01  1.422e-01  -4.005 6.64e-05 ***
CropTagetes            1.478e-01  1.380e-01   1.071 0.284283
CropTall_fescue       -5.666e-01  1.607e-01  -3.526 0.000440 ***
CropWhite_mustard      2.854e-01  9.892e-02   2.885 0.003989 **
CropWinter_barley     -3.513e-01  8.874e-02  -3.959 8.03e-05 ***
temperature_sum        2.003e-03  9.313e-05  21.513  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7409 on 1034 degrees of freedom
  (150 observations deleted due to missingness)
Multiple R-squared:  0.459,  Adjusted R-squared:  0.4537
F-statistic: 87.71 on 10 and 1034 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
                Sum Sq   Df  F value    Pr(>F)
(Intercept)     4425.1    1 8060.431 < 2.2e-16 ***
```

```
Crop            75.7    9   15.322 < 2.2e-16 ***
temperature_sum 254.1    1  462.792 < 2.2e-16 ***
Residuals       567.7 1034

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + radiation

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + radiation_mj_m2,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.6181 -0.3912  0.0408  0.4807  2.0905

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            5.797e+00  7.185e-02  80.684  < 2e-16 ***
CropBlack_oats         3.438e-01  7.112e-02   4.834 1.54e-06 ***
CropCommon_vetch      -3.665e-01  9.915e-02  -3.696 0.000231 ***
CropFodder_radish      5.239e-01  8.060e-02   6.499 1.25e-10 ***
CropItalian_ryegrass -3.940e-01  8.590e-02  -4.587 5.05e-06 ***
CropPhacelia          -2.374e-01  1.375e-01  -1.726 0.084689 .
CropTagetes            5.214e-01  1.271e-01   4.103 4.39e-05 ***
CropTall_fescue       -1.604e-01  1.564e-01  -1.026 0.305114
CropWhite_mustard      5.797e-01  9.306e-02   6.229 6.80e-10 ***
CropWinter_barley     -1.838e-01  8.663e-02  -2.121 0.034137 *
radiation_mj_m2        1.817e-03  7.714e-05  23.559  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7191 on 1034 degrees of freedom
  (150 observations deleted due to missingness)
Multiple R-squared:  0.4904, Adjusted R-squared:  0.4854
F-statistic: 99.49 on 10 and 1034 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
                Sum Sq   Df  F value    Pr(>F)
(Intercept)     3366.4    1 6509.889 < 2.2e-16 ***
Crop            126.6    9   27.202 < 2.2e-16 ***
radiation_mj_m2  287.0    1  555.013 < 2.2e-16 ***
Residuals        534.7 1034

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + week number

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + week number,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.4556 -0.3755  0.1104  0.4658  1.7494

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           14.799273   0.264259  56.003  < 2e-16 ***
CropBlack_oats         0.030445   0.070263   0.433   0.6649
CropCommon_vetch      -0.860625   0.098886  -8.703  < 2e-16 ***
CropFodder_radish     -0.069574   0.082640  -0.842   0.4000
CropItalian_ryegrass -0.461685   0.075777  -6.093 1.52e-09 ***
CropPhacelia          -0.696822   0.132104  -5.275 1.59e-07 ***
CropTagetes           -0.295363   0.134449  -2.197   0.0282 *
CropTall_fescue       -0.296649   0.155490  -1.908   0.0567 .
CropWhite_mustard      0.005212   0.093909   0.056   0.9557
CropWinter_barley     -0.147467   0.084057  -1.754   0.0796 .
week number            -0.208592   0.006793 -30.707  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7216 on 1133 degrees of freedom
  (51 observations deleted due to missingness)
Multiple R-squared:  0.5742, Adjusted R-squared:  0.5705
F-statistic: 152.8 on 10 and 1133 DF,  p-value: < 2.2e-16
```

```
Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
             Sum Sq   Df  F value    Pr(>F)
(Intercept) 1633.16    1 3136.336 < 2.2e-16 ***
Crop          82.37    9   17.576 < 2.2e-16 ***
week number  491.00    1  942.914 < 2.2e-16 ***
Residuals    589.98 1133

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 1

```
Analysis of Variance Table
Model 1: log(om_aboveground_kg_ha) ~ Crop
Model 2: log(om_aboveground_kg_ha) ~ Crop + week number
Model 3: log(om_aboveground_kg_ha) ~ Crop + temperature_sum
Model 4: log(om_aboveground_kg_ha) ~ Crop + radiation_mj_m2
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1   1035 821.72
2   1034 451.00  1    370.72 849.94 < 2.2e-16 ***
3   1034 567.65  0   -116.65
4   1034 534.71  0     32.94

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + crop height

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + average_crop_height_cm,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-2.63923 -0.35980  0.00292  0.36999  1.65799

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)             6.4500564  0.0840286  76.760  < 2e-16 ***
CropBlack_oats         -0.0978948  0.1027645  -0.953 0.341250
CropCommon_vetch       -0.4882733  0.1287942  -3.791 0.000168 ***
CropFodder_radish      -0.0551007  0.1141957  -0.483 0.629656
CropItalian_ryegrass   -0.0273802  0.1474215  -0.186 0.852735
CropPhacelia           -0.4988792  0.1348281  -3.700 0.000240 ***
CropTagetes             0.1987573  0.1524275   1.304 0.192857
CropTall_fescue        -0.0667293  0.1453291  -0.459 0.646321
CropWhite_mustard      -0.5333997  0.1310775  -4.069 5.48e-05 ***
CropWinter_barley      -0.4714901  0.1169026  -4.033 6.37e-05 ***
average_crop_height_cm  0.0180412  0.0007327  24.624  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5813 on 496 degrees of freedom
  (688 observations deleted due to missingness)
Multiple R-squared:  0.6964, Adjusted R-squared:  0.6903
F-statistic: 113.8 on 10 and 496 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
 Response: log(om_aboveground_kg_ha)
                        Sum Sq  Df   F value    Pr(>F)
(Intercept)            1991.10   1 5892.1375 < 2.2e-16 ***
Crop                     26.32   9    8.6555 4.178e-12 ***
average_crop_height_cm  204.89   1  606.3252 < 2.2e-16 ***
Residuals               167.61 496

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 2

```
Analysis of Variance Table

Model 1: log(om_aboveground_kg_ha) ~ Crop
Model 2: log(om_aboveground_kg_ha) ~ Crop + temperature_sum
Model 3: log(om_aboveground_kg_ha) ~ Crop + radiation_mj_m2
Model 4: log(om_aboveground_kg_ha) ~ Crop + week number
Model 5: log(om_aboveground_kg_ha) ~ Crop + average_crop_height_cm
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1    497 372.50
2    496 157.58  1   214.919 676.46 < 2.2e-16 ***
```

```
3    496 142.23  0    15.355
4    496 161.98  0   -19.748
5    496 167.61  0    -5.633

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Only crop + week number + moisture

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + week number +
    moisture_availability_mm, data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.8016 -0.3666  0.0638  0.4296  1.4752

Coefficients:
                           Estimate Std. Error t value Pr(>|t|)
(Intercept)              13.9840268  0.2640274  52.964  < 2e-16 ***
CropBlack_oats           -0.1617327  0.0661669  -2.444  0.01468 *
CropCommon_vetch         -1.0310597  0.0931407 -11.070  < 2e-16 ***
CropFodder_radish        -0.1932251  0.0780160  -2.477  0.01342 *
CropItalian_ryegrass     -0.2155025  0.0765384  -2.816  0.00496 **
CropPhacelia             -0.9396999  0.1253612  -7.496 1.41e-13 ***
CropTagetes              -0.4932498  0.1257236  -3.923 9.31e-05 ***
CropTall_fescue          -0.3304312  0.1402473  -2.356  0.01866 *
CropWhite_mustard        -0.1279941  0.0891771  -1.435  0.15151
CropWinter_barley        -0.3557176  0.0785255  -4.530 6.59e-06 ***
week number               -0.1794055  0.0070112 -25.588  < 2e-16 ***
moisture_availability_mm -0.0016830  0.0002344  -7.180 1.33e-12 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6449 on 1033 degrees of freedom
  (150 observations deleted due to missingness)
Multiple R-squared:  0.5906, Adjusted R-squared:  0.5862
F-statistic: 135.5 on 11 and 1033 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
                          Sum Sq   Df  F value    Pr(>F)
(Intercept)              1166.52    1 2805.218 < 2.2e-16 ***
Crop                       75.62    9   20.206 < 2.2e-16 ***
week number               272.28    1  654.771 < 2.2e-16 ***
moisture_availability_mm   21.44    1   51.556 1.329e-12 ***
Residuals                 429.56 1033

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Only crop + week number + soil type

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + week number +
    soil_type, data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.5400 -0.3237  0.0771  0.4598  1.6316

Coefficients:
                             Estimate Std. Error t value Pr(>|t|)
(Intercept)                  14.58357    0.26009  56.072  < 2e-16 ***
CropBlack_oats                0.07757    0.06903   1.124 0.261370
CropCommon_vetch             -0.66735    0.09857  -6.770 2.06e-11 ***
CropFodder_radish             0.08189    0.08237   0.994 0.320347
CropItalian_ryegrass         -0.43575    0.07321  -5.952 3.53e-09 ***
CropPhacelia                 -0.44031    0.13241  -3.325 0.000911 ***
CropTagetes                  -0.30880    0.12985  -2.378 0.017569 *
CropTall_fescue              -0.36858    0.15030  -2.452 0.014345 *
CropWhite_mustard             0.21022    0.09442   2.226 0.026190 *
CropWinter_barley            -0.20638    0.08142  -2.535 0.011389 *
week number                   -0.20109    0.00670 -30.014  < 2e-16 ***
soil_typeClay                -0.42734    0.05733  -7.454 1.80e-13 ***
soil_typeLoam                -0.63749    0.10072  -6.329 3.55e-10 ***
soil_typeReclaimed peat soil  0.04138    0.10253   0.404 0.686635

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 0.6961 on 1130 degrees of freedom
  (51 observations deleted due to missingness)
Multiple R-squared:  0.6048, Adjusted R-squared:  0.6003
F-statistic:   133 on 13 and 1130 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
             Sum Sq   Df  F value    Pr(>F)
(Intercept) 1523.59    1 3144.071 < 2.2e-16 ***
Crop          76.22    9   17.476 < 2.2e-16 ***
week number   436.55    1  900.865 < 2.2e-16 ***
soil_type      42.39    3   29.158 < 2.2e-16 ***
Residuals     547.59 1130

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Only crop + week number + fertilization

```
lm(formula = log(om_aboveground_kg_ha) ~ Crop + week number +
    n_fertilisation_kg_ha, data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.5574 -0.3467  0.0769  0.4790  1.4473

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           13.514370   0.305650  44.215  < 2e-16 ***
CropBlack_oats       -0.003089   0.065981  -0.047  0.96267
CropCommon_vetch     -0.879425   0.093296  -9.426  < 2e-16 ***
CropFodder_radish    -0.083749   0.078099  -1.072  0.28381
CropItalian_ryegrass -0.227393   0.077314  -2.941  0.00334 **
CropPhacelia         -0.700149   0.123625  -5.663 1.91e-08 ***
CropTagetes          -0.285800   0.125485  -2.278  0.02295 *
CropTall_fescue      -0.340641   0.143601  -2.372  0.01786 *
CropWhite_mustard    -0.009398   0.089183  -0.105  0.91609
CropWinter_barley    -0.201265   0.079448  -2.533  0.01144 *
week number           -0.173925   0.007788 -22.333  < 2e-16 ***
n_fertilisation_kg_ha  0.004508   0.001045   4.314 1.75e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6617 on 1055 degrees of freedom
  (128 observations deleted due to missingness)
Multiple R-squared:  0.5678, Adjusted R-squared:  0.5633
F-statistic:   126 on 11 and 1055 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(om_aboveground_kg_ha)
                      Sum Sq   Df  F value    Pr(>F)
(Intercept)           856.10    1 1954.980 < 2.2e-16 ***
Crop                  63.68    9   16.157 < 2.2e-16 ***
week number            218.41    1  498.762 < 2.2e-16 ***
n_fertilisation_kg_ha   8.15    1   18.612 1.752e-05 ***
Residuals             461.99 1055

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 3

```
Analysis of Variance Table
Model 1: log(om_aboveground_kg_ha) ~ Crop + week number
Model 2: log(om_aboveground_kg_ha) ~ Crop + week number + soil_type
Model 3: log(om_aboveground_kg_ha) ~ Crop + week number + n_fertilisation_kg_ha
Model 4: log(om_aboveground_kg_ha) ~ Crop + week number + moisture_availability_mm
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1   1034 451.00
2   1032 422.92  2    28.082 34.263 3.918e-15 ***
3   1033 443.34 -1   -20.422 49.834 3.067e-12 ***
4   1033 429.56  0    13.779

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

7.4.2 Models for shoot root OM ratio

Only Crop

```
lm(formula = log(shoot_root_ratio_om) ~ Crop, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-7.2445 -0.4676  0.0188  0.5655  2.1335

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)            -0.1876     0.1575  -1.191 0.234200
CropBlack_oats          0.9450     0.1769   5.343 1.52e-07 ***
CropCommon_vetch        1.1658     0.1997   5.837 1.08e-08 ***
CropFodder_radish       1.2983     0.1782   7.287 1.64e-12 ***
CropItalian_ryegrass    0.3070     0.2208   1.391 0.165106
CropPhacelia            1.5531     0.3749   4.143 4.17e-05 ***
CropTagetes             1.0362     0.2172   4.770 2.57e-06 ***
CropTall_fescue        -1.0200     0.2875  -3.548 0.000434 ***
CropWhite_mustard       1.7329     0.2006   8.640  < 2e-16 ***
CropWinter_barley      -0.0475     0.2611  -0.182 0.855772

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8333 on 410 degrees of freedom
  (775 observations deleted due to missingness)
Multiple R-squared:  0.3359, Adjusted R-squared:  0.3213
F-statistic: 23.04 on 9 and 410 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_om)
             Sum Sq  Df F value Pr(>F)
(Intercept)   0.986   1  1.4194 0.2342
Crop        144.015   9 23.0445 <2e-16 ***
Residuals   284.696 410

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + OM above

```
lm(formula = log(shoot_root_ratio_om) ~ Crop + om_aboveground_kg_ha,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.9585 -0.3444  0.0303  0.4151  1.7890

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)          -4.738e-01  1.407e-01  -3.368 0.000828 ***
CropBlack_oats        8.144e-01  1.558e-01   5.229 2.73e-07 ***
CropCommon_vetch      1.134e+00  1.754e-01   6.466 2.88e-10 ***
CropFodder_radish     9.122e-01  1.603e-01   5.692 2.40e-08 ***
CropItalian_ryegrass  1.157e-01  1.946e-01   0.595 0.552390
CropPhacelia          1.244e+00  3.303e-01   3.766 0.000190 ***
CropTagetes           2.646e-01  2.031e-01   1.303 0.193267
CropTall_fescue      -8.267e-01  2.530e-01  -3.267 0.001178 **
CropWhite_mustard     1.295e+00  1.805e-01   7.177 3.39e-12 ***
CropWinter_barley     1.197e-01  2.298e-01   0.521 0.602584
om_aboveground_kg_ha   1.904e-04  1.718e-05  11.082  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7317 on 409 degrees of freedom
  (775 observations deleted due to missingness)
Multiple R-squared:  0.4893, Adjusted R-squared:  0.4768
F-statistic: 39.18 on 10 and 409 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_om)
                      Sum Sq  Df F value    Pr(>F)
(Intercept)            6.073   1  11.345 0.0008281 ***
Crop                  93.093   9  19.322 < 2.2e-16 ***
om_aboveground_kg_ha  65.748   1 122.819 < 2.2e-16 ***
Residuals            218.948 409
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + temperature

```
lm(formula = log(shoot_root_ratio_om) ~ Crop + temperature_sum,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-7.0317 -0.4603  0.0419  0.5227  2.0680

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.6025186  0.1819483  -3.311 0.001013 **
CropBlack_oats         1.0575291  0.1773537   5.963 5.46e-09 ***
CropCommon_vetch       1.1890768  0.1993610   5.964 5.41e-09 ***
CropFodder_radish      1.3253670  0.1784502   7.427 6.79e-13 ***
CropItalian_ryegrass   0.2101012  0.2225517   0.944 0.345713
CropPhacelia           1.1726493  0.4401460   2.664 0.008029 **
CropTagetes            0.7900813  0.2257616   3.500 0.000518 ***
CropTall_fescue       -0.8972535  0.2849040  -3.149 0.001760 **
CropWhite_mustard      1.6877536  0.2012534   8.386 8.75e-16 ***
CropWinter_barley      0.1479595  0.2612168   0.566 0.571424
temperature_sum        0.0005999  0.0001434   4.185 3.51e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8189 on 399 degrees of freedom
  (785 observations deleted due to missingness)
Multiple R-squared:  0.3666, Adjusted R-squared:  0.3507
F-statistic: 23.09 on 10 and 399 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_om)
                 Sum Sq  Df F value    Pr(>F)
(Intercept)       7.354   1  10.966  0.001013 **
Crop            132.647   9  21.977 < 2.2e-16 ***
temperature_sum  11.744   1  17.512 3.515e-05 ***
Residuals       267.585 399

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + radiation

```
lm(formula = log(shoot_root_ratio_om) ~ Crop + temperature_sum,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-7.0317 -0.4603  0.0419  0.5227  2.0680

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.6025186  0.1819483  -3.311 0.001013 **
CropBlack_oats         1.0575291  0.1773537   5.963 5.46e-09 ***
CropCommon_vetch       1.1890768  0.1993610   5.964 5.41e-09 ***
CropFodder_radish      1.3253670  0.1784502   7.427 6.79e-13 ***
CropItalian_ryegrass   0.2101012  0.2225517   0.944 0.345713
CropPhacelia           1.1726493  0.4401460   2.664 0.008029 **
CropTagetes            0.7900813  0.2257616   3.500 0.000518 ***
CropTall_fescue       -0.8972535  0.2849040  -3.149 0.001760 **
CropWhite_mustard      1.6877536  0.2012534   8.386 8.75e-16 ***
CropWinter_barley      0.1479595  0.2612168   0.566 0.571424
temperature_sum        0.0005999  0.0001434   4.185 3.51e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8189 on 399 degrees of freedom
  (785 observations deleted due to missingness)
Multiple R-squared:  0.3666, Adjusted R-squared:  0.3507
F-statistic: 23.09 on 10 and 399 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_om)
                 Sum Sq  Df F value    Pr(>F)
```

```
(Intercept)      13.483   1  21.211  5.54e-06 ***
Crop            120.828   9  21.121 < 2.2e-16 ***
radiation_mj_m2  25.705   1  40.438  5.56e-10 ***
Residuals       253.625 399

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + week number

```
lm(formula = log(shoot_root_ratio_om) ~ Crop + week number, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-6.9126 -0.4549  0.0291  0.5356  2.0645

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)            2.43047    0.47374   5.130 4.48e-07 ***
CropBlack_oats        0.96811    0.17012   5.691 2.42e-08 ***
CropCommon_vetch      0.98139    0.19463   5.042 6.93e-07 ***
CropFodder_radish     1.14676    0.17371   6.602 1.27e-10 ***
CropItalian_ryegrass  0.12010    0.21469   0.559  0.57619
CropPhacelia          1.27037    0.36369   3.493  0.00053 ***
CropTagetes           0.55213    0.22478   2.456  0.01445 *
CropTall_fescue      -0.81101    0.27876  -2.909  0.00382 **
CropWhite_mustard     1.55506    0.19525   7.964 1.67e-14 ***
CropWinter_barley     0.24289    0.25598   0.949  0.34326
week number            -0.07375    0.01264  -5.832 1.11e-08 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8012 on 408 degrees of freedom
  (776 observations deleted due to missingness)
Multiple R-squared:  0.3885, Adjusted R-squared:  0.3735
F-statistic: 25.92 on 10 and 408 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_om)
                 Sum Sq  Df F value    Pr(>F)
(Intercept)      13.483   1  21.211  5.54e-06 ***
Crop            120.828   9  21.121 < 2.2e-16 ***
radiation_mj_m2  25.705   1  40.438  5.56e-10 ***
Residuals       253.625 399

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 4

```
Analysis of Variance Table

Model 1: log(shoot_root_ratio_om) ~ Crop
Model 2: log(shoot_root_ratio_om) ~ Crop + om_aboveground_kg_ha
Model 3: log(shoot_root_ratio_om) ~ Crop + temperature_sum
Model 4: log(shoot_root_ratio_om) ~ Crop + radiation_mj_m2
Model 5: log(shoot_root_ratio_om) ~ Crop + week number
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1    400 279.33
2    399 215.80  1    63.528 117.46 < 2.2e-16 ***
3    399 267.58  0   -51.784
4    399 253.62  0    13.961
5    399 258.08  0    -4.459

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

7.4.3 Models for N uptake aboveground

Only crop

```
lm(formula = log(n_uptake_kg_ha) ~ Crop, data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-3.2390 -0.4562 -0.0193  0.4726  1.9372
```

```
Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)            3.32258    0.05410  61.416  < 2e-16 ***
CropBlack_oats         0.04192    0.07857   0.534 0.593745
CropCommon_vetch       0.43828    0.11488   3.815 0.000145 ***
CropFodder_radish      0.81832    0.09322   8.778  < 2e-16 ***
CropItalian_ryegrass -0.08361    0.08760  -0.954 0.340110
CropPhacelia           0.25563    0.13644   1.874 0.061325 .
CropTagetes            1.10131    0.18522   5.946 3.94e-09 ***
CropTall_fescue       -0.48819    0.16267  -3.001 0.002765 **
CropWhite_mustard      0.80690    0.10327   7.814 1.56e-14 ***
CropWinter_barley     -0.44989    0.08878  -5.068 4.90e-07 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7516 on 894 degrees of freedom
  (291 observations deleted due to missingness)
Multiple R-squared:  0.2407, Adjusted R-squared:  0.2331
F-statistic:  31.5 on 9 and 894 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(n_uptake_kg_ha)
             Sum Sq  Df  F value    Pr(>F)
(Intercept) 2130.62   1 3771.969 < 2.2e-16 ***
Crop         160.11   9   31.495 < 2.2e-16 ***
Residuals    504.98 894

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + temperature

```
lm(formula = log(n_uptake_kg_ha) ~ Crop + temperature_sum, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-3.01395 -0.40042  0.00458  0.43105  1.77284

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            2.528e+00  6.392e-02  39.550  < 2e-16 ***
CropBlack_oats         1.543e-02  6.742e-02   0.229 0.819075
CropCommon_vetch      -3.399e-02  1.021e-01  -0.333 0.739224
CropFodder_radish      5.382e-01  8.340e-02   6.453 1.82e-10 ***
CropItalian_ryegrass -2.606e-01  7.599e-02  -3.429 0.000635 ***
CropPhacelia          -7.066e-02  1.268e-01  -0.557 0.577508
CropTagetes            2.126e-03  1.696e-01   0.013 0.990000
CropTall_fescue       -5.873e-01  1.390e-01  -4.225 2.64e-05 ***
CropWhite_mustard      4.629e-01  9.349e-02   4.951 8.87e-07 ***
CropWinter_barley     -3.869e-01  7.675e-02  -5.041 5.65e-07 ***
temperature_sum        1.797e-03  9.964e-05  18.038  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6406 on 863 degrees of freedom
  (321 observations deleted due to missingness)
Multiple R-squared:  0.4494, Adjusted R-squared:  0.4431
F-statistic: 70.45 on 10 and 863 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(n_uptake_kg_ha)
                Sum Sq  Df  F value    Pr(>F)
(Intercept)     642.01   1 1564.223 < 2.2e-16 ***
Crop             70.97   9   19.212 < 2.2e-16 ***
temperature_sum 133.55   1  325.380 < 2.2e-16 ***
Residuals       354.20 863

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + radiation

```
lm(formula = log(n_uptake_kg_ha) ~ Crop + radiation_mj_m2, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)

Residuals:
```

```
    Min      1Q  Median      3Q     Max 
-3.4209 -0.3821 -0.0199  0.4310  2.0991 

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)    
(Intercept)            2.581e+00  7.393e-02  34.915  < 2e-16 ***
CropBlack_oats        2.075e-01  7.287e-02   2.848 0.004510 ** 
CropCommon_vetch      3.006e-01  1.059e-01   2.838 0.004651 ** 
CropFodder_radish     8.511e-01  8.733e-02   9.746  < 2e-16 ***
CropItalian_ryegrass -3.106e-01  8.209e-02  -3.783 0.000165 ***
CropPhacelia          2.161e-01  1.344e-01   1.607 0.108320    
CropTagetes           7.075e-01  1.713e-01   4.130 3.98e-05 ***
CropTall_fescue      -2.984e-01  1.488e-01  -2.005 0.045271 *  
CropWhite_mustard     7.691e-01  9.741e-02   7.895 8.79e-15 ***
CropWinter_barley    -2.969e-01  8.255e-02  -3.596 0.000341 ***
radiation_mj_m2        1.152e-03  8.575e-05  13.432  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6837 on 863 degrees of freedom
  (321 observations deleted due to missingness)
Multiple R-squared:  0.3729, Adjusted R-squared:  0.3657 
F-statistic: 51.33 on 10 and 863 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(n_uptake_kg_ha)
                Sum Sq  Df  F value    Pr(>F)    
(Intercept)     569.86   1 1219.064 < 2.2e-16 ***
Crop           133.86   9   31.818 < 2.2e-16 ***
radiation_mj_m2  84.33   1  180.411 < 2.2e-16 ***
Residuals       403.41 863                       

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + week number

```
lm(formula = log(n_uptake_kg_ha) ~ Crop + week number, data = gb_v5, 
    weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max 
-2.95618 -0.38642  0.04673  0.44683  1.60458 

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)            8.676668   0.271244  31.988  < 2e-16 ***
CropBlack_oats        -0.008657   0.065364  -0.132  0.89467    
CropCommon_vetch      -0.128577   0.099609  -1.291  0.19710    
CropFodder_radish      0.375030   0.080600   4.653 3.77e-06 ***
CropItalian_ryegrass -0.229241   0.073184  -3.132  0.00179 ** 
CropPhacelia          -0.209533   0.115784  -1.810  0.07068 .  
CropTagetes           -0.169552   0.166554  -1.018  0.30896    
CropTall_fescue       -0.444899   0.135248  -3.289  0.00104 ** 
CropWhite_mustard      0.294049   0.089590   3.282  0.00107 ** 
CropWinter_barley     -0.336203   0.074020  -4.542 6.34e-06 ***
week number            -0.140801   0.007034 -20.016  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6248 on 893 degrees of freedom
  (291 observations deleted due to missingness)
Multiple R-squared:  0.4759, Adjusted R-squared:   0.47 
F-statistic: 81.08 on 10 and 893 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(n_uptake_kg_ha)
            Sum Sq  Df  F value    Pr(>F)    
(Intercept) 399.44   1 1023.256 < 2.2e-16 ***
Crop        43.02   9   12.246 < 2.2e-16 ***
week number  156.39   1  400.642 < 2.2e-16 ***
Residuals   348.59 893                       

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 5

```
Analysis of Variance Table

Model 1: log(n_uptake_kg_ha) ~ Crop
Model 2: log(n_uptake_kg_ha) ~ Crop + week number
Model 3: log(n_uptake_kg_ha) ~ Crop + radiation_mj_m2
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1    864 487.75
2    863 337.28  1   150.465 384.99 < 2.2e-16 ***
3    863 403.41  0   -66.131

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + crop height

```
lm(formula = log(n_uptake_kg_ha) ~ Crop + average_crop_height_cm,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-2.34114 -0.34578 -0.03521  0.35592  1.48876

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)             2.903908   0.079964  36.315  < 2e-16 ***
CropBlack_oats         0.009423   0.101301   0.093   0.9259
CropCommon_vetch       0.061476   0.128408   0.479   0.6324
CropFodder_radish      0.493848   0.116613   4.235 2.81e-05 ***
CropItalian_ryegrass  -0.186393   0.140003  -1.331   0.1838
CropPhacelia           0.061329   0.133766   0.458   0.6468
CropTagetes            0.441162   0.176968   2.493   0.0131 *
CropTall_fescue       -0.160892   0.138015  -1.166   0.2444
CropWhite_mustard     -0.049848   0.135955  -0.367   0.7141
CropWinter_barley     -0.254603   0.111019  -2.293   0.0223 *
average_crop_height_cm  0.013372   0.001081  12.367  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5521 on 420 degrees of freedom
  (764 observations deleted due to missingness)
Multiple R-squared:  0.5086, Adjusted R-squared:  0.4969
F-statistic: 43.48 on 10 and 420 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(n_uptake_kg_ha)
                       Sum Sq  Df  F value    Pr(>F)
(Intercept)            401.92   1 1318.7907 < 2.2e-16 ***
Crop                   18.30    9    6.6704 6.097e-09 ***
average_crop_height_cm  46.61   1  152.9518 < 2.2e-16 ***
Residuals              128.00 420

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Comparison 6

```
Analysis of Variance Table
Model 1: log(n_uptake_kg_ha) ~ Crop
Model 2: log(n_uptake_kg_ha) ~ Crop + temperature_sum
Model 3: log(n_uptake_kg_ha) ~ Crop + radiation_mj_m2
Model 4: log(n_uptake_kg_ha) ~ Crop + week number
Model 5: log(n_uptake_kg_ha) ~ Crop + average_crop_height_cm
  Res.Df    RSS Df Sum of Sq      F    Pr(>F)
1    421 174.61
2    420 127.02  1    47.592 157.37 < 2.2e-16 ***
3    420 130.95  0    -3.930
4    420 122.86  0     8.097
5    420 128.00  0    -5.145

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

7.4.4 Models for shoot root N uptake ratio

Only crop

```
lm(formula = log(shoot_root_ratio_n_uptake) ~ Crop, data = gb_v5,
    weights = gb_v5$weight_repetitions_above)
```

```
Residuals:
     Min       1Q   Median       3Q      Max 
-1.78035 -0.37222  0.02335  0.41645  2.22407 

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)    
(Intercept)            -0.1540     0.1951  -0.790 0.430802    
CropBlack_oats          0.9875     0.2108   4.686 5.31e-06 ***
CropCommon_vetch        0.4346     0.3598   1.208 0.228581    
CropFodder_radish       1.6695     0.2231   7.482 2.64e-12 ***
CropItalian_ryegrass    0.5100     0.3598   1.418 0.157956    
CropPhacelia            1.7333     0.3598   4.818 2.96e-06 ***
CropTagetes             0.8168     0.2519   3.242 0.001400 ** 
CropTall_fescue        -0.9607     0.2759  -3.482 0.000618 ***
CropWhite_mustard       2.1735     0.2581   8.421 9.00e-15 ***
CropWinter_barley       0.1808     0.2581   0.700 0.484602    

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6759 on 190 degrees of freedom
  (995 observations deleted due to missingness)
Multiple R-squared:  0.5678, Adjusted R-squared:  0.5473 
F-statistic: 27.73 on 9 and 190 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_n_uptake)
             Sum Sq  Df F value Pr(>F)    
(Intercept)   0.285   1  0.6233 0.4308    
Crop        114.035   9 27.7341 <2e-16 ***
Residuals    86.803 190                   

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + n uptake aboveground

```
lm(formula = log(shoot_root_ratio_n_uptake) ~ Crop + n_uptake_kg_ha, 
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.95150 -0.38958  0.05533  0.43790  1.84352 

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)           -0.229963   0.192596  -1.194 0.233966    
CropBlack_oats         0.939342   0.206889   4.540 9.98e-06 ***
CropCommon_vetch       0.318911   0.354189   0.900 0.369055    
CropFodder_radish      1.420720   0.233106   6.095 6.03e-09 ***
CropItalian_ryegrass   0.535879   0.352258   1.521 0.129864    
CropPhacelia           1.480417   0.361769   4.092 6.32e-05 ***
CropTagetes            0.584889   0.257995   2.267 0.024519 *  
CropTall_fescue       -0.929409   0.270286  -3.439 0.000719 ***
CropWhite_mustard      2.043430   0.256218   7.975 1.41e-13 ***
CropWinter_barley      0.199234   0.252720   0.788 0.431474    
n_uptake_kg_ha         0.003489   0.001143   3.053 0.002595 ** 

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6616 on 189 degrees of freedom
  (995 observations deleted due to missingness)
Multiple R-squared:  0.5881, Adjusted R-squared:  0.5663 
F-statistic: 26.99 on 10 and 189 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_n_uptake)
               Sum Sq  Df F value    Pr(>F)    
(Intercept)     0.624   1  1.4257  0.233966    
Crop           82.699   9 20.9937 < 2.2e-16 ***
n_uptake_kg_ha  4.079   1  9.3185  0.002595 ** 
Residuals      82.724 189                      

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + temperature

```
lm(formula = log(shoot_root_ratio_n_uptake) ~ Crop + temperature_sum,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-1.67314 -0.36913  0.01831  0.42815  1.79873

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.0298464  0.2087820  -0.143 0.886481
CropBlack_oats         1.0271489  0.2062163   4.981 1.45e-06 ***
CropCommon_vetch       0.0408829  0.3955154   0.103 0.917784
CropFodder_radish      1.7245871  0.2205083   7.821 3.87e-13 ***
CropItalian_ryegrass   0.5568168  0.3503192   1.589 0.113665
CropPhacelia           1.7720962  0.3955154   4.480 1.30e-05 ***
CropTagetes            1.0360782  0.2898261   3.575 0.000447 ***
CropTall_fescue       -0.9261645  0.2685952  -3.448 0.000699 ***
CropWhite_mustard      2.2298539  0.2553515   8.732 1.46e-15 ***
CropWinter_barley      0.1758120  0.2502145   0.703 0.483160
temperature_sum       -0.0003260  0.0002321  -1.404 0.161885

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6552 on 185 degrees of freedom
  (999 observations deleted due to missingness)
Multiple R-squared:  0.5921, Adjusted R-squared:  0.5701
F-statistic: 26.86 on 10 and 185 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_n_uptake)
                Sum Sq  Df F value Pr(>F)
(Intercept)      0.009   1  0.0204 0.8865
Crop           115.272   9 29.8401 <2e-16 ***
temperature_sum  0.847   1  1.9723 0.1619
Residuals       79.406 185

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + radiation

```
lm(formula = log(shoot_root_ratio_n_uptake) ~ Crop + radiation_mj_m2,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-1.66807 -0.36284  0.02547  0.43772  1.82271

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.0058214  0.2163706   0.027 0.978565
CropBlack_oats         0.9924045  0.2041252   4.862 2.48e-06 ***
CropCommon_vetch       0.0116942  0.3879789   0.030 0.975987
CropFodder_radish      1.6903318  0.2172027   7.782 4.88e-13 ***
CropItalian_ryegrass   0.5624519  0.3501360   1.606 0.109896
CropPhacelia           1.7429075  0.3879789   4.492 1.24e-05 ***
CropTagetes            0.9831365  0.2674712   3.676 0.000311 ***
CropTall_fescue       -0.9676207  0.2672681  -3.620 0.000380 ***
CropWhite_mustard      2.2089566  0.2538369   8.702 1.76e-15 ***
CropWinter_barley      0.1610803  0.2503069   0.644 0.520677
radiation_mj_m2       -0.0003311  0.0002183  -1.517 0.131051

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6546 on 185 degrees of freedom
  (999 observations deleted due to missingness)
Multiple R-squared:  0.5929, Adjusted R-squared:  0.5709
F-statistic: 26.94 on 10 and 185 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_n_uptake)
                Sum Sq  Df F value Pr(>F)
(Intercept)      0.000   1  0.0007 0.9786
Crop           115.384   9 29.9214 <2e-16 ***
radiation_mj_m2  0.986   1  2.3004 0.1311
```

```
Residuals        79.267 185
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Crop + week number

```
lm(formula = log(shoot_root_ratio_n_uptake) ~ Crop + week number,
    data = gb_v5, weights = gb_v5$weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-1.79712 -0.37719  0.03295  0.41348  2.22011

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.042109   0.715951   0.059 0.953161
CropBlack_oats        0.973711   0.216776   4.492 1.23e-05 ***
CropCommon_vetch      0.396016   0.385242   1.028 0.305280
CropFodder_radish     1.648678   0.235297   7.007 4.17e-11 ***
CropItalian_ryegrass  0.503159   0.361458   1.392 0.165550
CropPhacelia          1.694744   0.385242   4.399 1.81e-05 ***
CropTagetes           0.764330   0.312520   2.446 0.015373 *
CropTall_fescue      -0.966941   0.277464  -3.485 0.000612 ***
CropWhite_mustard     2.154241   0.267476   8.054 8.78e-14 ***
CropWinter_barley     0.180036   0.258757   0.696 0.487428
week number            -0.004956   0.017399  -0.285 0.776098

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6776 on 189 degrees of freedom
  (995 observations deleted due to missingness)
Multiple R-squared:  0.568,  Adjusted R-squared:  0.5451
F-statistic: 24.85 on 10 and 189 DF,  p-value: < 2.2e-16

Anova Table (Type III tests)
Response: log(shoot_root_ratio_n_uptake)
             Sum Sq  Df F value Pr(>F)
(Intercept)   0.002   1  0.0035 0.9532
Crop       105.825   9 25.6129 <2e-16 ***
week number    0.037   1  0.0811 0.7761
Residuals     86.766 189
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

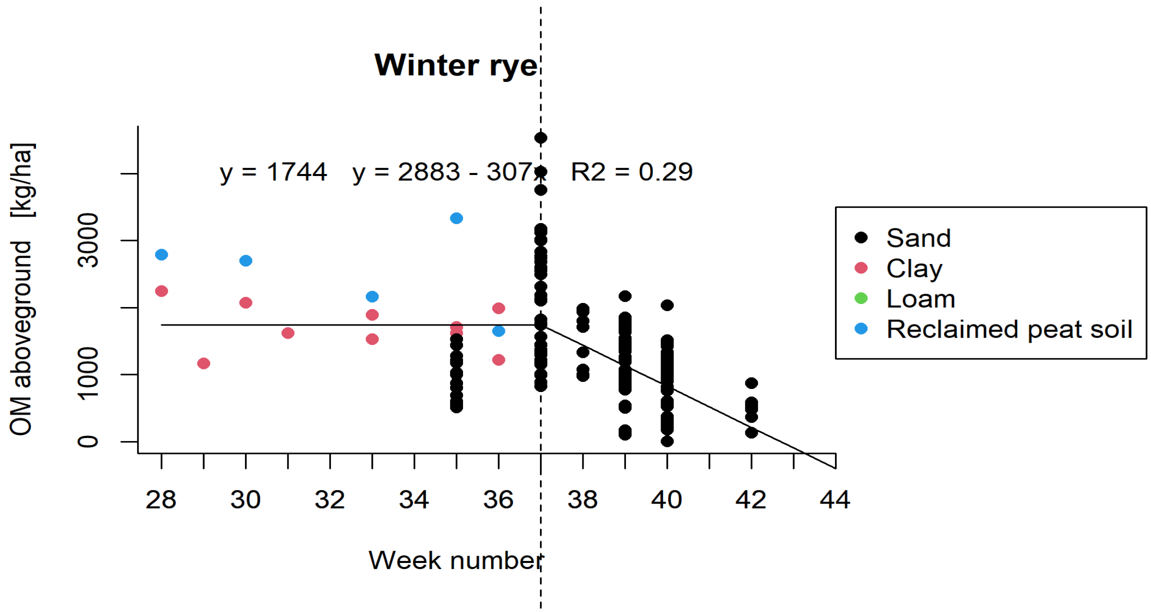
Comparison 7

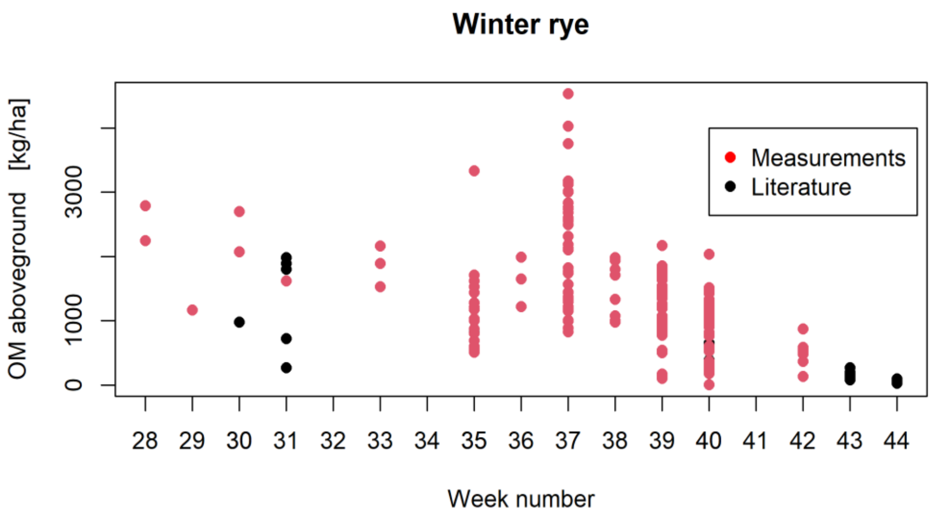
```
Analysis of Variance Table
Model 1: log(shoot_root_ratio_n_uptake) ~ Crop
Model 2: log(shoot_root_ratio_n_uptake) ~ Crop + n_uptake_kg_ha
Model 3: log(shoot_root_ratio_n_uptake) ~ Crop + week number
Model 4: log(shoot_root_ratio_n_uptake) ~ Crop + temperature_sum
Model 5: log(shoot_root_ratio_n_uptake) ~ Crop + radiation_mj_m2
  Res.Df    RSS Df Sum of Sq      F   Pr(>F)
1    186 80.253
2    185 77.974  1   2.27857 5.4061 0.02115 *
3    185 80.229  0  -2.25460
4    185 79.406  0   0.82257
5    185 79.267  0   0.13910

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

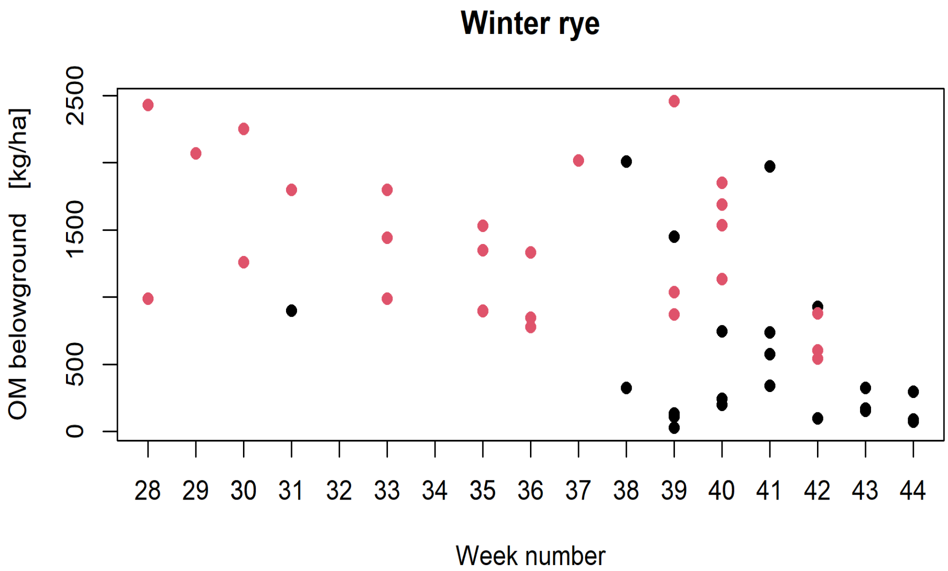
7.5 OM aboveground vs. week number

7.5.1 Winter rye

```
 ***Regression Model with Segmented Relationship(s)***
segmented.lm(obj = om_w_rye_lm_basis)

Estimated Break-Point(s):
                 Est. St.Err
psi1.week number   37  0.685
Meaningful coefficients of the linear terms:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    2883.15    1036.45   2.782  0.00597 **
week number     -30.78      29.82  -1.032  0.30336
U1.week number -275.79      71.76  -3.843       NA

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 835.2 on 184 degrees of freedom
Multiple R-Squared: 0.3011,  Adjusted R-squared: 0.2897

Convergence attained in 1 iter. (rel. change 6.9344e-06)

$week number
           Est. St.Err. t value CI(95%).l CI(95%).u
slope1  -30.777  29.819 -1.0321   -89.608    28.053
slope2 -306.560  65.275 -4.6965  -435.350  -177.780
 Davies' test for a change in the slope
data:  formula = om_aboveground_kg_ha ~ week number ,   method = lm
model = gaussian , link = identity
segmented variable = week number
'best' at = 37.333, n.points = 8, p-value = 0.0004367
alternative hypothesis: two.sided
```

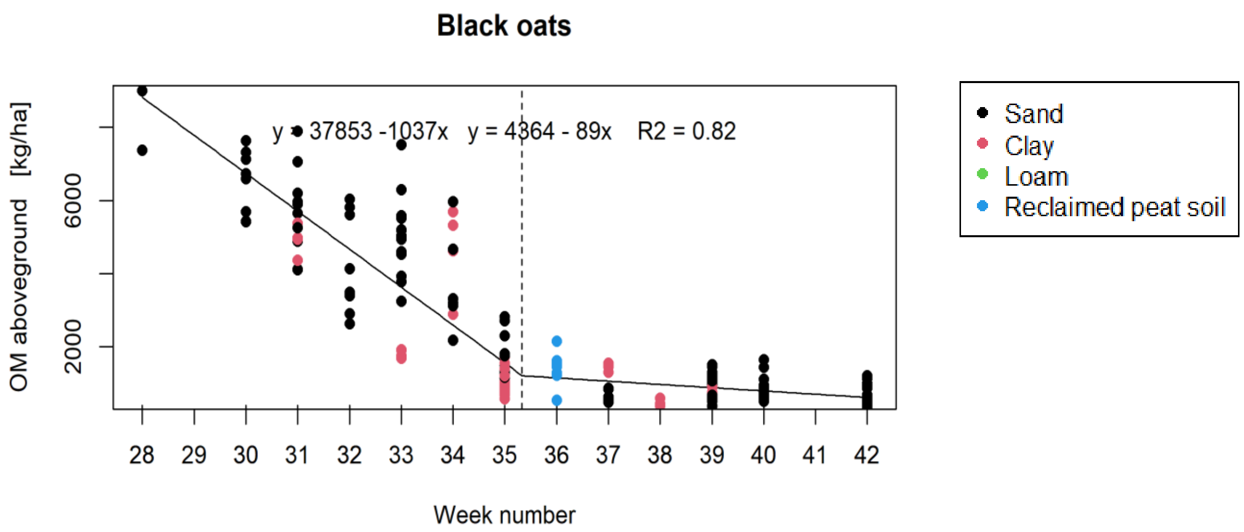



Winter rye
OM aboveground [kg/ha]
0
1000
3000
Measurements
Literature
28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44
Week number


Winter rye
OM belowground [kg/ha]
0
500
1500
2500
28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44
Week number

7.5.2 Black oats

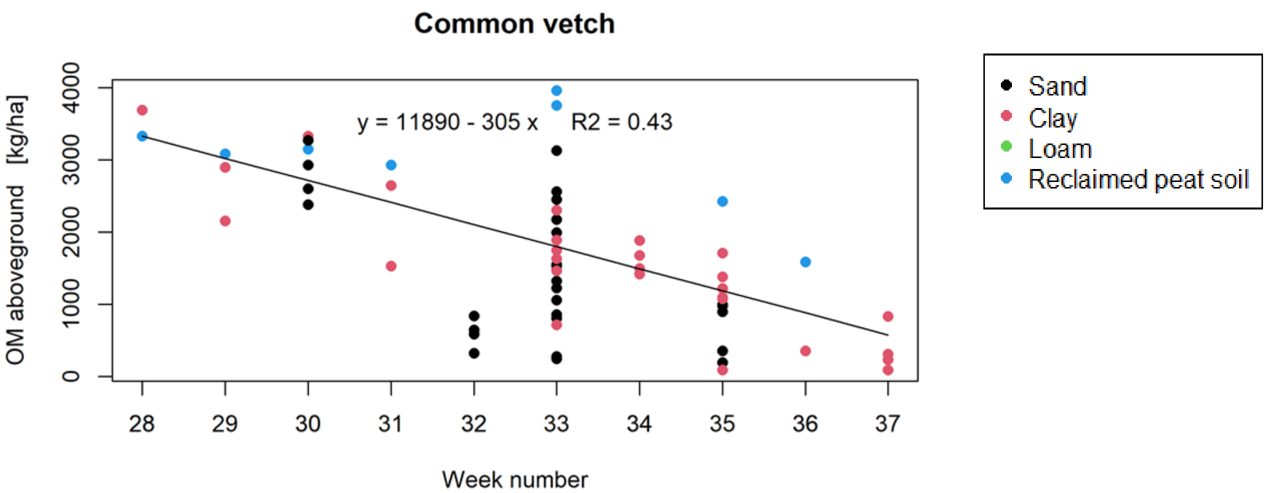
```
 ***Regression Model with Segmented Relationship(s)***

segmented.lm(obj = om_b_oats_lm_basis)

Estimated Break-Point(s):
                   Est. St.Err
psi1.week number 35.333  0.255

Meaningful coefficients of the linear terms:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   37845.85    1435.68   26.36   <2e-16 ***
week number   -1036.81      43.10  -24.06   <2e-16 ***
U1.week number   947.60      61.65   15.37       NA

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 880.7 on 221 degrees of freedom
Multiple R-Squared: 0.8262,  Adjusted R-squared: 0.8238

Convergence attained in 2 iter. (rel. change 0)

$week number
            Est. St.Err.  t value CI(95%).l CI(95%).u
slope1 -1036.800  43.098 -24.0570  -1121.70 -951.8700
slope2   -89.208  44.083  -2.0236   -176.08   -2.3316


 Davies' test for a change in the slope

data:  formula = om_aboveground_kg_ha ~ week number ,   method = lm
model = gaussian , link = identity
segmented variable = week number
'best' at = 35.778, n.points = 8, p-value < 2.2e-16
alternative hypothesis: two.sided
```

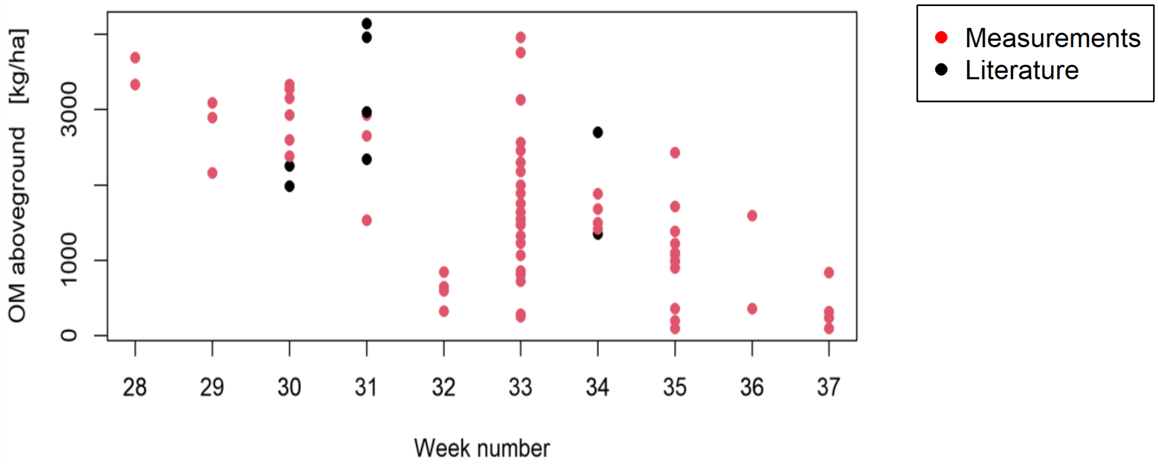


7.5.3 Common vetch

Restricted to data until week 37

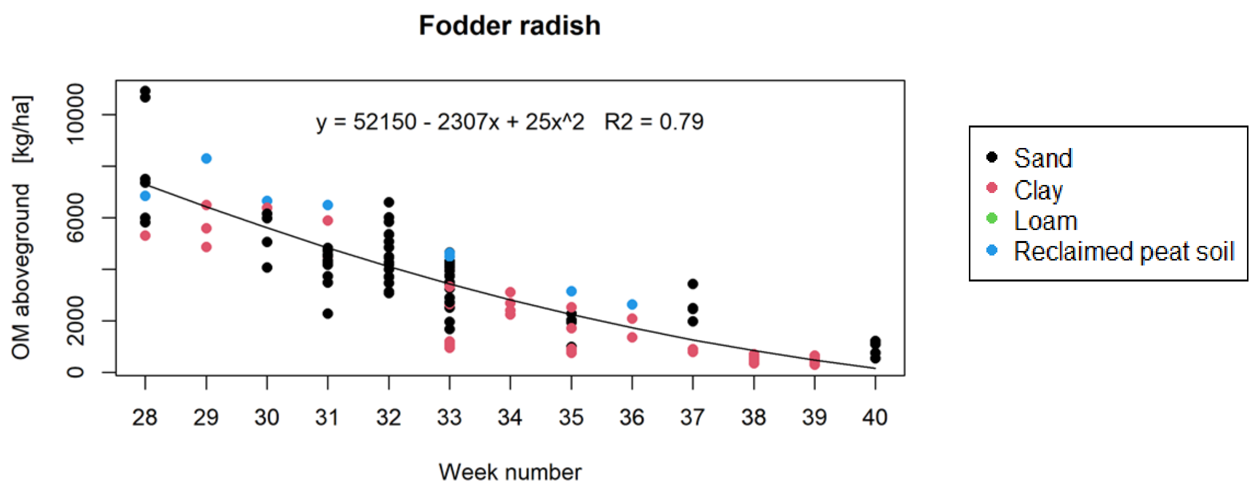
```
lm(formula = om_aboveground_kg_ha ~ week number, data = c_vetch_data,
    weights = c_vetch_data$weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max 
-1905.5  -657.1  -119.6   381.9  3738.5 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 11890.77    1446.00   8.223 1.82e-11 ***
week number  -305.73      44.28  -6.904 3.38e-09 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1084 on 61 degrees of freedom
  (148 observations deleted due to missingness)
Multiple R-squared:  0.4387, Adjusted R-squared:  0.4295 
F-statistic: 47.67 on 1 and 61 DF,  p-value: 3.382e-09
```

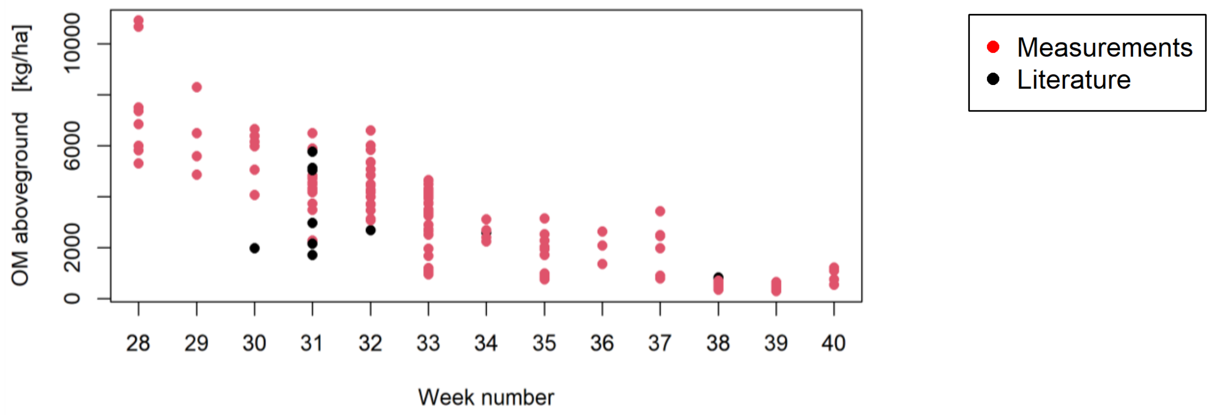




7.5.4 Fodder radish

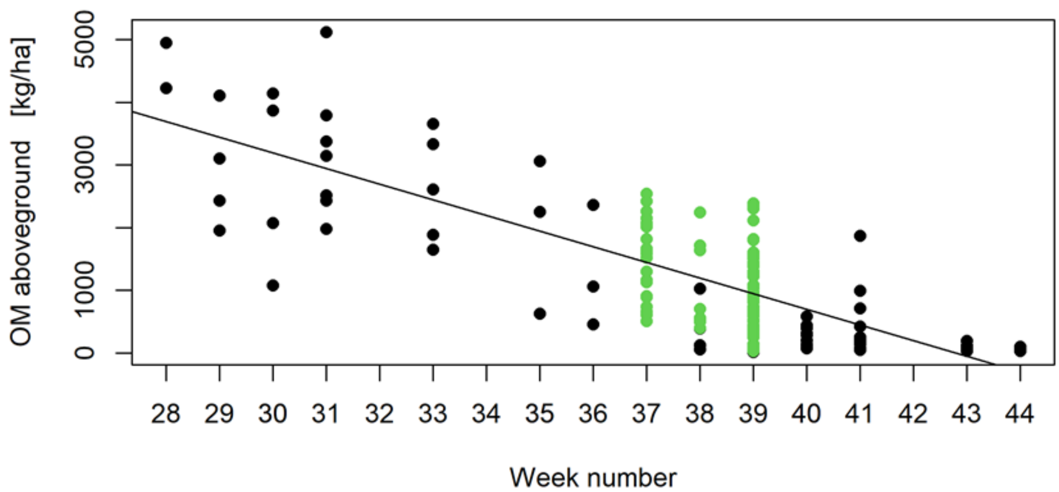
```
lm(formula = om_aboveground_kg_ha ~ week number + week2, data = f_radish_data,
    weights = f_radish_data$weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-3435.5  -532.9  -184.0   475.2  3620.4

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 52149.566   8967.338   5.816 4.02e-08 ***
week number  -2306.714    533.906  -4.320 2.96e-05 ***
week2           25.168      7.893   3.189  0.00177 **

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1169 on 138 degrees of freedom
  (148 observations deleted due to missingness)
Multiple R-squared:  0.7943, Adjusted R-squared:  0.7914
F-statistic: 266.5 on 2 and 138 DF,  p-value: < 2.2e-16
```





7.5.5 *Italian ryegrass*

The data from Italian Ryegrass undersowing (in green) seems to fit quite well into the data from Italian Ryegrass in general. We fitted a linear model for the Italian Ryegrass data.

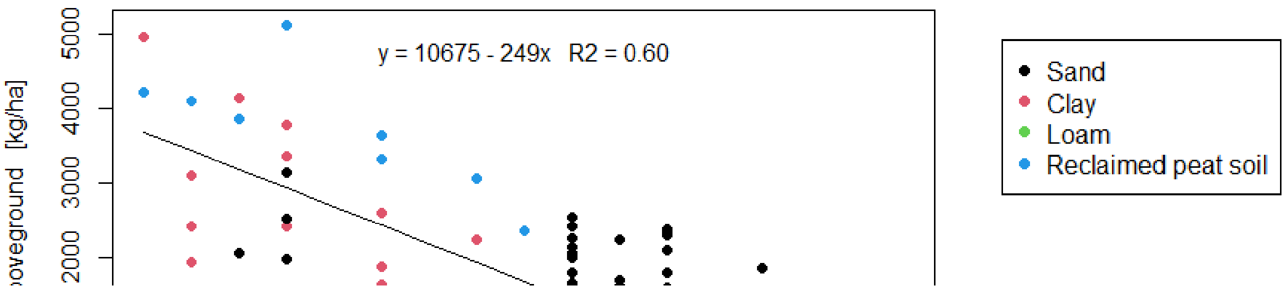


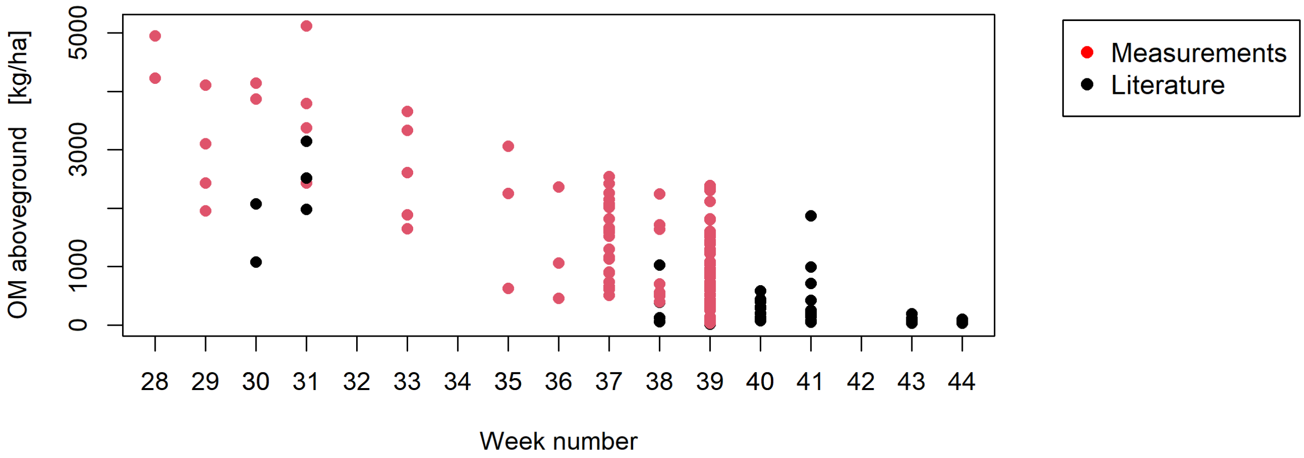
Subsequently we predicted from the model the mean value for week 37, 38, 39 and tested with t-test whether the mean for Italian Ryegrass undersowing is significantly different from the predictions for these weeks (the data is roughly normally distributed, not shown here). We can conclude that it is not the case and therefore we will join both sets of Italian Ryegrass into one.

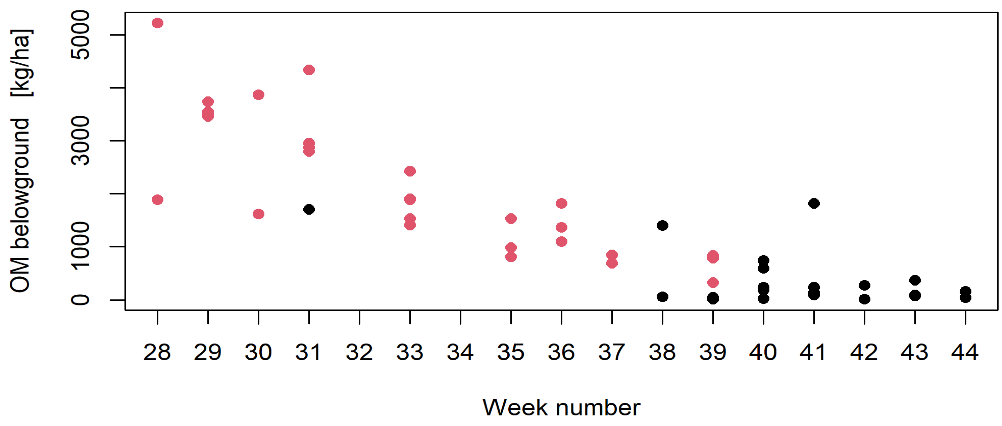
```
 One Sample t-test
data:  gb_v3$om_aboveground_kg_ha[itrgr$week number == 37]
t = 4.5671, df = 163, p-value = 9.709e-06
alternative hypothesis: true mean is not equal to 1444.1
95 percent confidence interval:
 1788.244 2312.505
sample estimates:
mean of x
 2050.375
 One Sample t-test
data:  gb_v3$om_aboveground_kg_ha[itrgr$week number == 38]
t = 3.4358, df = 92, p-value = 0.0008884
alternative hypothesis: true mean is not equal to 1194.617
95 percent confidence interval:
 1411.046 2004.063
sample estimates:
mean of x
 1707.555
 One sample t-test
data:  gb_v3$om_aboveground_kg_ha[itrgr$week number == 39]
t = 10.164, df = 392, p-value < 2.2e-16
alternative hypothesis: true mean is not equal to 945.1335
95 percent confidence interval:
 1648.487 1985.831
sample estimates:
mean of x
 1817.159
```

```
lm(formula = om_aboveground_kg_ha ~ week number, data = it_ryegr_data,
    weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-3655.5  -725.9  -286.6   650.5  3767.9

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10674.98     613.77   17.39   <2e-16 ***
week number   -249.48      16.22  -15.38   <2e-16 ***
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1206 on 158 degrees of freedom
  (23 observations deleted due to missingness)
Multiple R-squared:  0.5995, Adjusted R-squared:  0.597
F-statistic: 236.5 on 1 and 158 DF,  p-value: < 2.2e-16
```

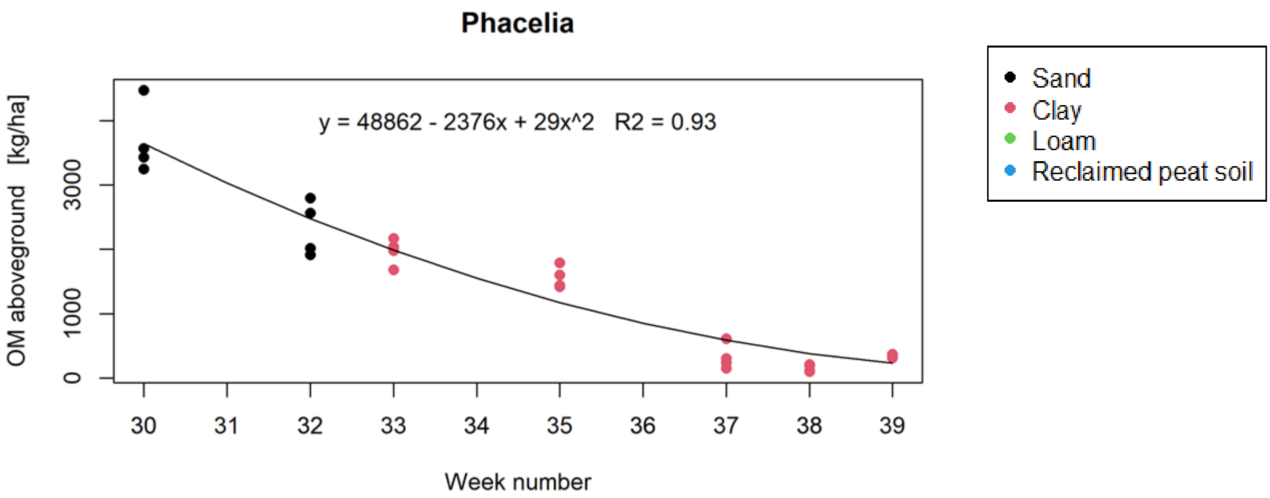


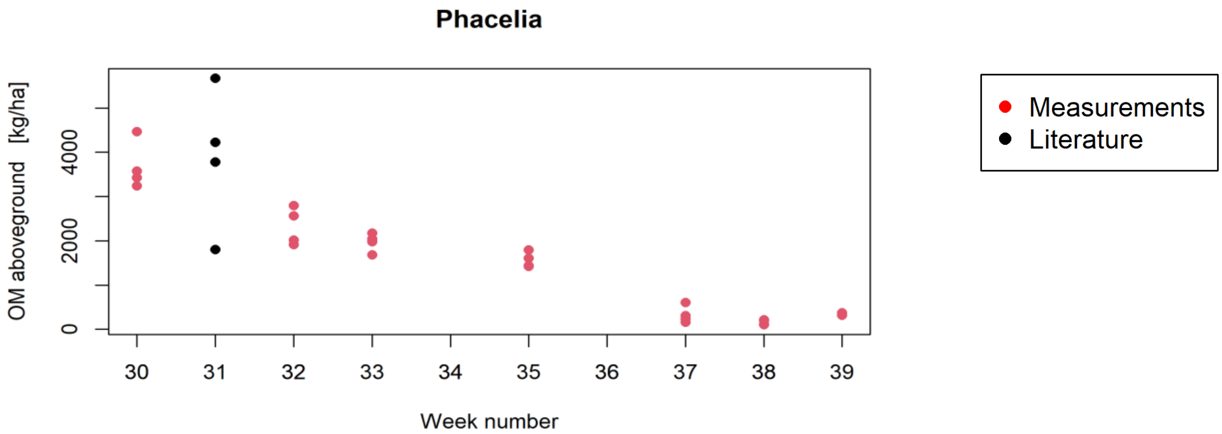




7.5.6 Phacelia

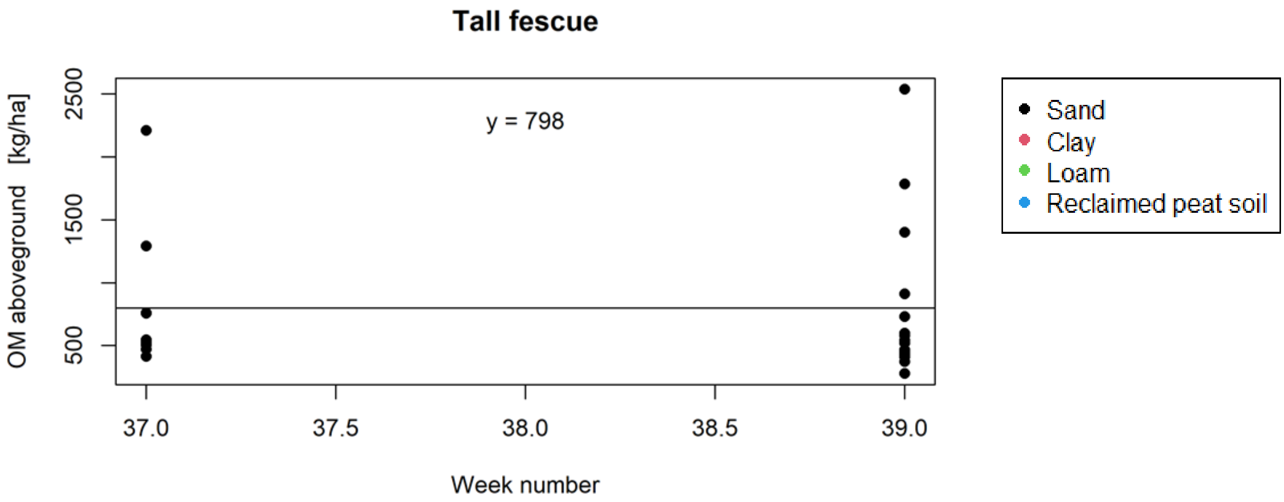
```
lm(formula = om_aboveground_kg_ha ~ week_number + week2, data = phac_data,
    weights = phac_data$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-561.33 -270.92   67.87  133.69  826.72

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 48862.957   9146.894   5.342 9.81e-06 ***
week_number  -2375.825    528.870  -4.492 0.000104 ***
week2           28.948      7.588   3.815 0.000660 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 325.6 on 29 degrees of freedom
  (148 observations deleted due to missingness)
Multiple R-squared:  0.9345, Adjusted R-squared:   0.93
F-statistic: 206.8 on 2 and 29 DF,  p-value: < 2.2e-16
```





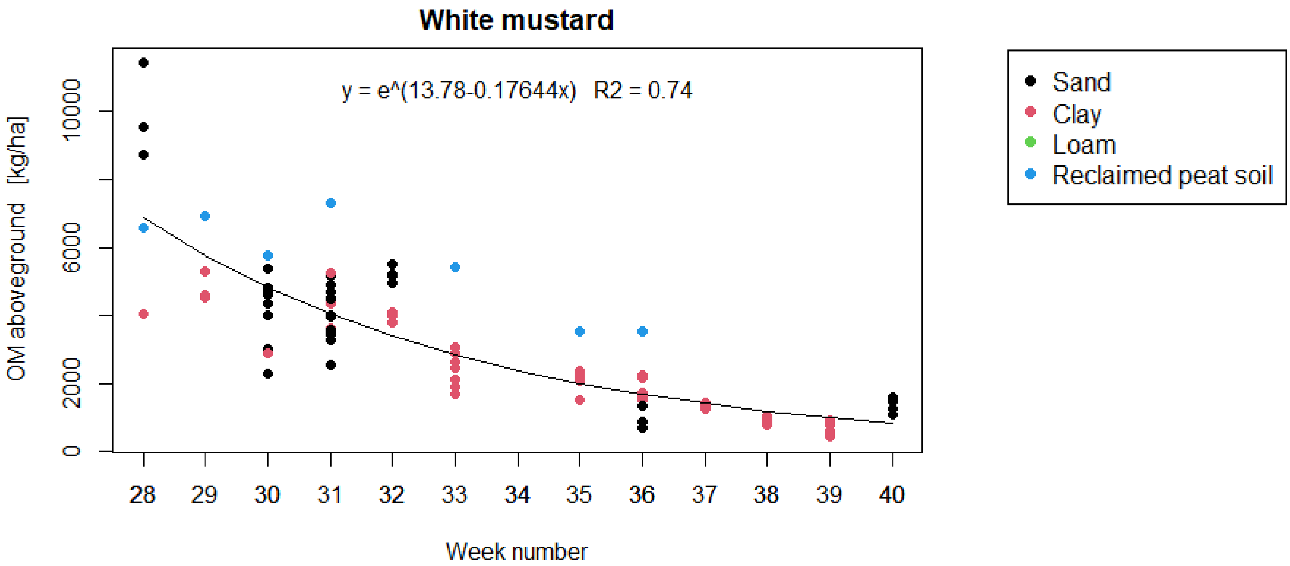
7.5.7 Tall fescue

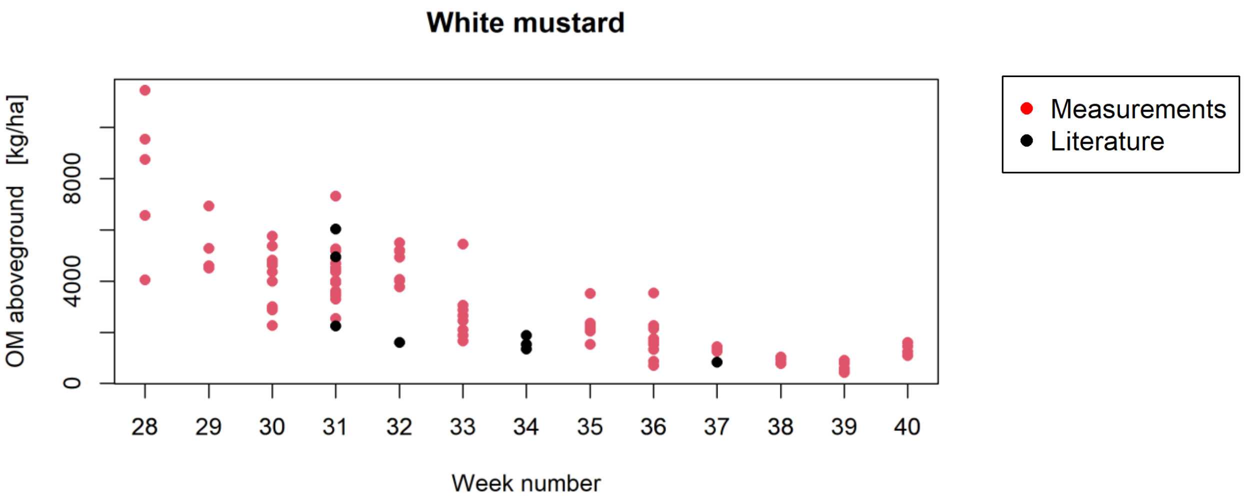
```
lm(formula = om_aboveground_kg_ha ~ 1, data = t_fesc_data, weights = t_fesc_data$weight_repetitions_above)

Residuals:
   Min     1Q Median     3Q    Max 
-519.9 -341.6 -254.2  -37.5 1737.1 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)    797.9      118.4   6.738 5.72e-07 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 592.1 on 24 degrees of freedom
  (148 observations deleted due to missingness)
```



7.5.8 White mustard

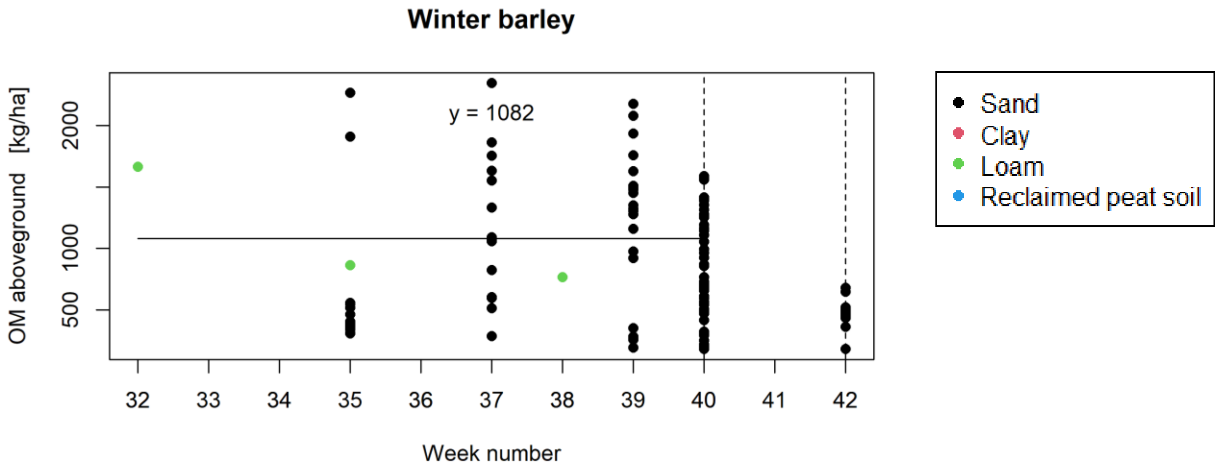
```
lm(formula = log(om_aboveground_kg_ha) ~ week number, data = w_must_data,
    weights = weight_repetitions_above)

Weighted Residuals:
     Min       1Q   Median       3Q      Max
-0.92005 -0.21008 -0.01987  0.19835  1.28964

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 13.77801    0.36619   37.62   <2e-16 ***
week number  -0.17644    0.01105  -15.97   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4278 on 88 degrees of freedom
  (148 observations deleted due to missingness)
Multiple R-squared:  0.7436, Adjusted R-squared:  0.7406
F-statistic: 255.2 on 1 and 88 DF,  p-value: < 2.2e-16
```



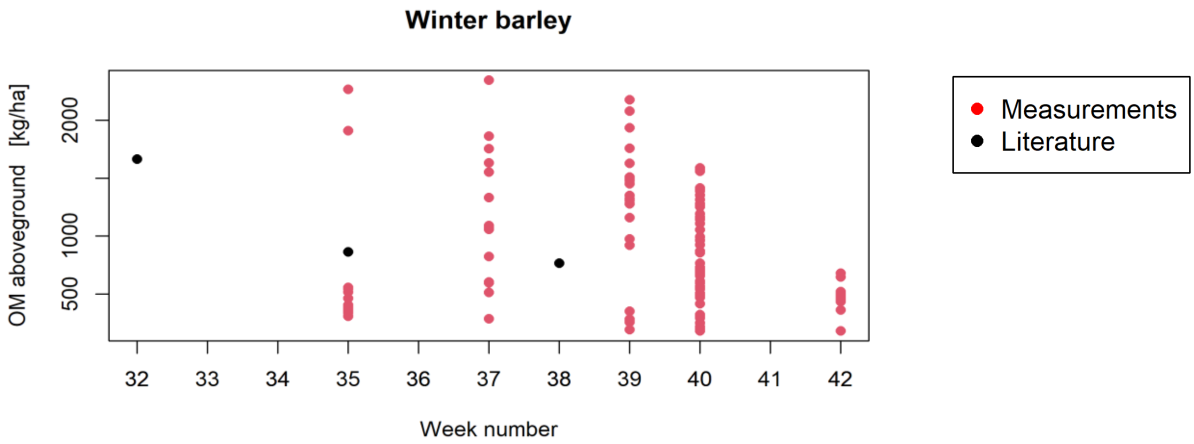


7.5.9 Winter barley

```
lm(formula = om_aboveground_kg_ha ~ 1, data = w_barl_data[w_barl_data$week number <
    40, ], weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-1850.6  -683.8   -23.5   428.7  3397.3

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  1082.37      67.88   15.95   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 836.8 on 52 degrees of freedom
  (8 observations deleted due to missingness)
```

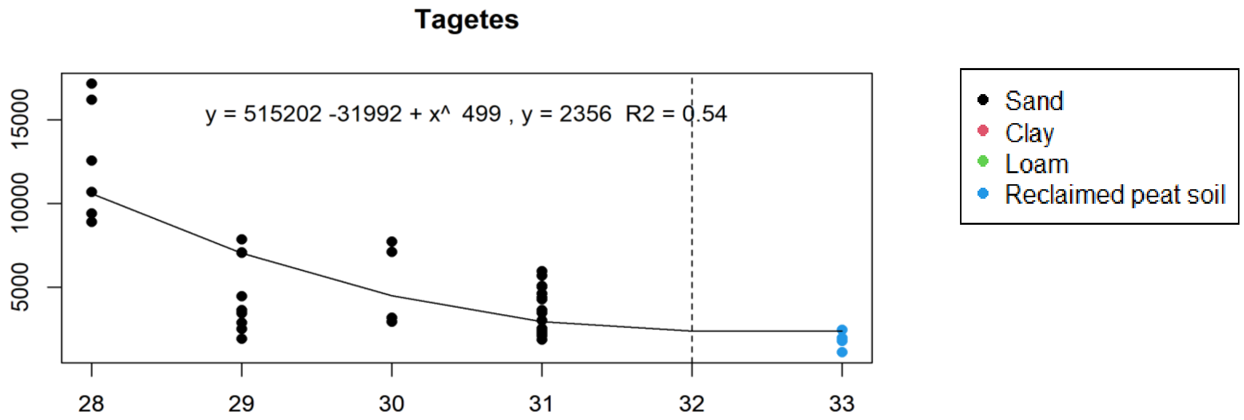


Week number < 40: 1082.37 kg OM/ha
Week number = 40: 747.7194 kg OM/ha
Week number = 42: 475.47 kg OM/ha



7.5.10 Tagetes

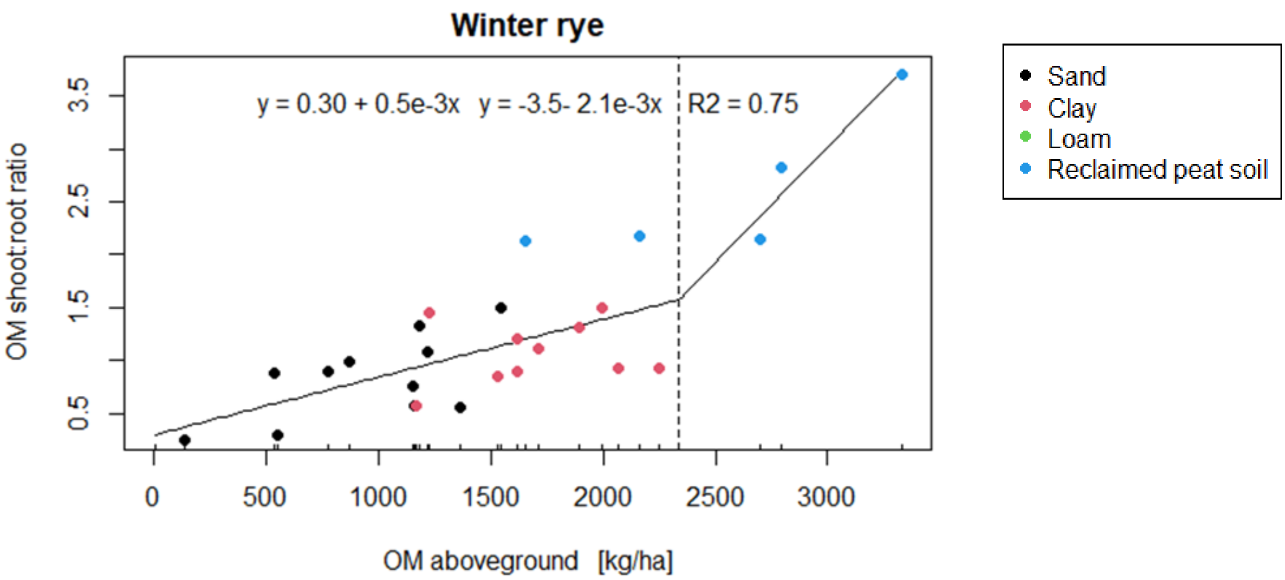
```
lm(formula = om_aboveground_kg_ha ~ week number + week2, data = tag_data,
    weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-5106.3 -1233.8  -347.7  1586.9  6560.7

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 515201.9   157265.6   3.276  0.00233 **
week number -31991.6    10390.5  -3.079  0.00396 **
week2          498.9      171.3   2.912  0.00614 **

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2586 on 36 degrees of freedom
  (157 observations deleted due to missingness)
Multiple R-squared:  0.5651, Adjusted R-squared:  0.5409
F-statistic: 23.39 on 2 and 36 DF,  p-value: 3.101e-07
```



7.6 Shoot:root ratio OM vs. OM aboveground

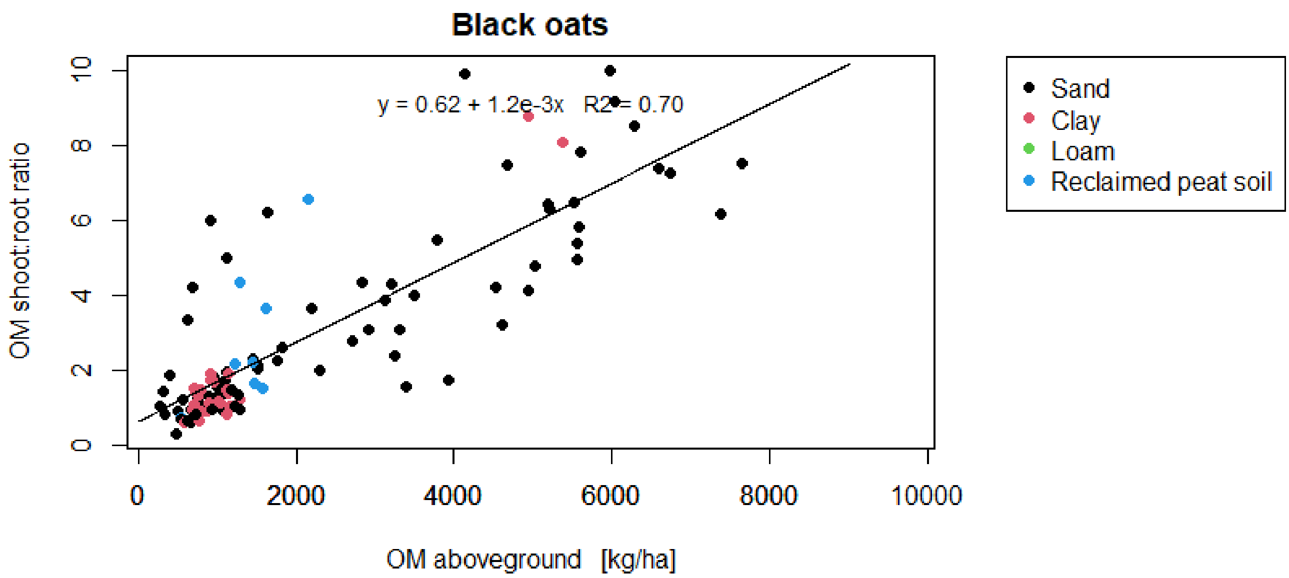
7.6.1 Winter rye

```
 ***Regression Model with Segmented Relationship(s)***
segmented.lm(obj = srom_w_rye_lm)
Estimated Break-Point(s):
                              Est.  St.Err
psi1.om_aboveground_kg_ha 2336.448 320.043
Meaningful coefficients of the linear terms:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)               0.2974974  0.2755166   1.080  0.29143
om_aboveground_kg_ha      0.0005454  0.0001709   3.191  0.00406 **
U1.om_aboveground_kg_ha 0.0016337  0.0007656   2.134       NA
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6229 on 23 degrees of freedom
Multiple R-Squared: 0.7747,  Adjusted R-squared: 0.7454
Convergence attained in 2 iter. (rel. change 0)

$om_aboveground_kg_ha
             Est.    St.Err. t value  CI(95%).l  CI(95%).u
slope1 0.00054541 0.00017091  3.1913 0.00019186 0.00089896
slope2 0.00217910 0.00074631  2.9198 0.00063524 0.00372300
 Davies' test for a change in the slope
data:  formula = shoot_root_ratio_om ~ om_aboveground_kg_ha ,   method = lm
model = gaussian , link = identity
segmented variable = om_aboveground_kg_ha
'best' at = 2495.1, n.points = 10, p-value = 0.01629
alternative hypothesis: two.sided
```



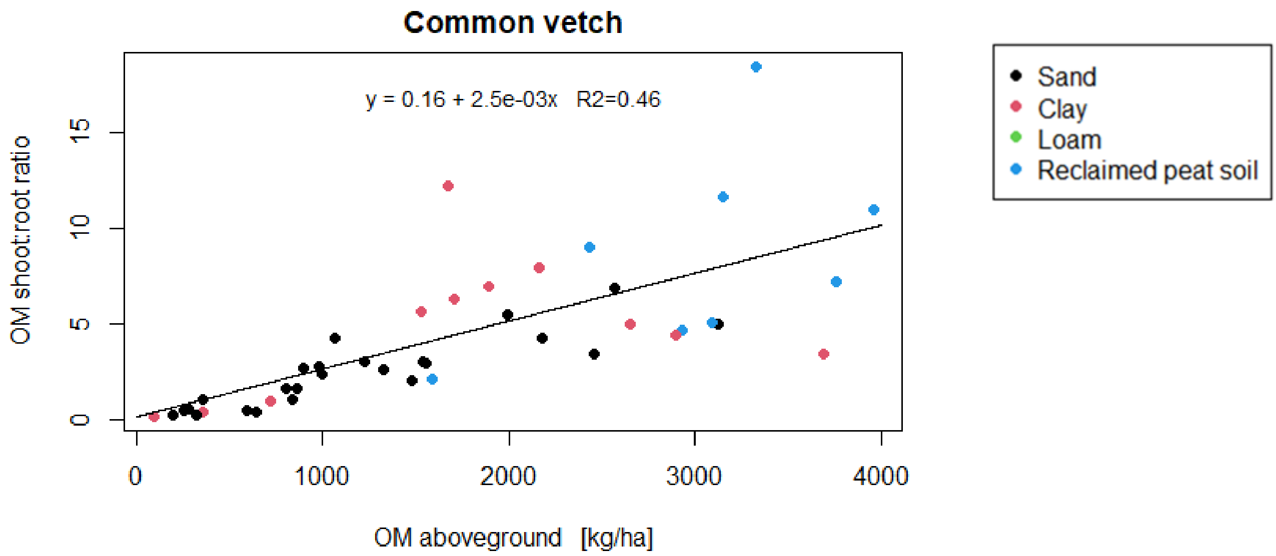
7.6.2 Black oats

```
lm(formula = shoot_root_ratio_om ~ om_aboveground_kg_ha, data = b_oats_data,
    weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-3.0523 -0.6450 -0.2995  0.1437  4.8885

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          6.248e-01  1.993e-01   3.135  0.00223 **
om_aboveground_kg_ha 1.062e-03  6.818e-05  15.579  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.367 on 105 degrees of freedom
  (273 observations deleted due to missingness)
Multiple R-squared:  0.698,  Adjusted R-squared:  0.6951
F-statistic: 242.7 on 1 and 105 DF,  p-value: < 2.2e-16
```



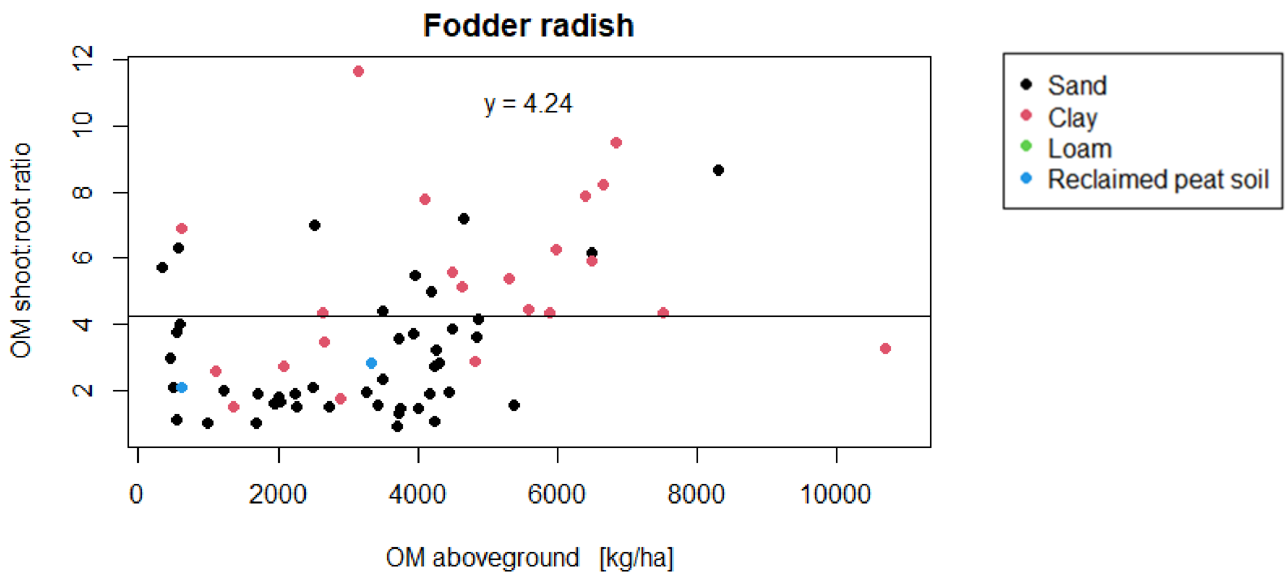
7.6.3 Common vetch

```
lm(formula = shoot_root_ratio_om ~ om_aboveground_kg_ha, data = c_vetch_data,
    weights = weight_repetitions_above)

Weighted Residuals:
     Min       1Q   Median       3Q      Max
-10.3769  -1.5231  -0.5120   0.3431  17.3104

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          0.1628375  0.9437510   0.173    0.864
om_aboveground_kg_ha 0.0025054  0.0004128   6.070 3.44e-07 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 4.228 on 41 degrees of freedom
  (171 observations deleted due to missingness)
Multiple R-squared:  0.4733, Adjusted R-squared:  0.4605
F-statistic: 36.84 on 1 and 41 DF,  p-value: 3.441e-07
```



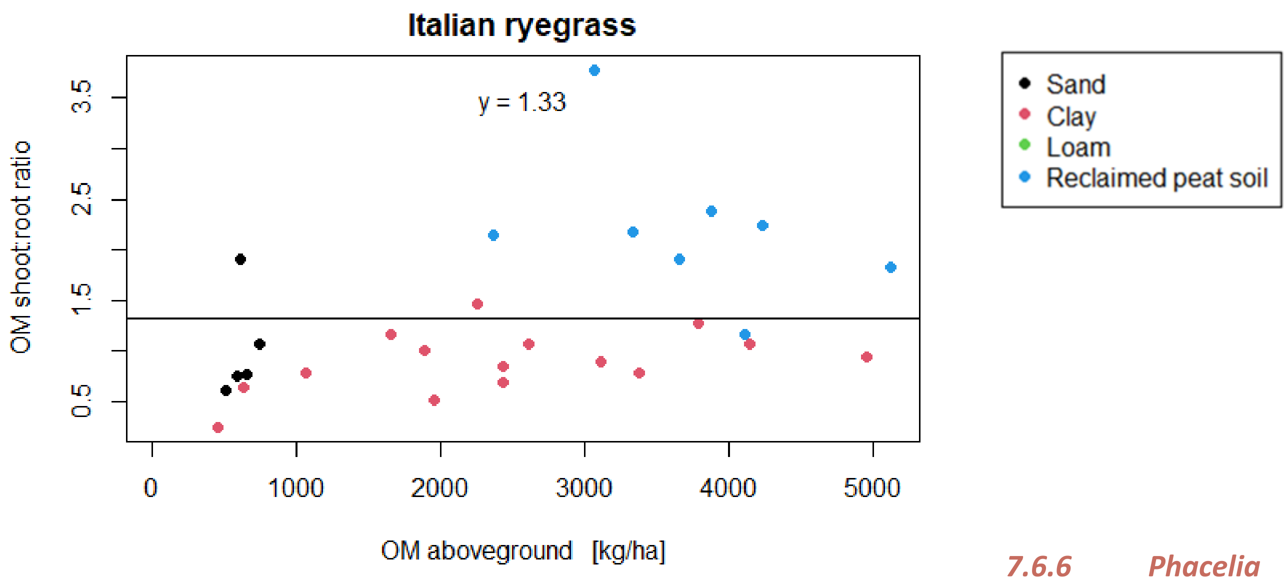
7.6.4 Fodder radish

```
lm(formula = shoot_root_ratio_om ~ 1, data = f_radish_data, weights = weight_repetitions_above)

Weighted Residuals:
   Min     1Q Median     3Q    Max
-4.696 -2.377 -1.376  1.357 12.871

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   4.2358     0.2528   16.75   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.013 on 95 degrees of freedom
  (196 observations deleted due to missingness)
```

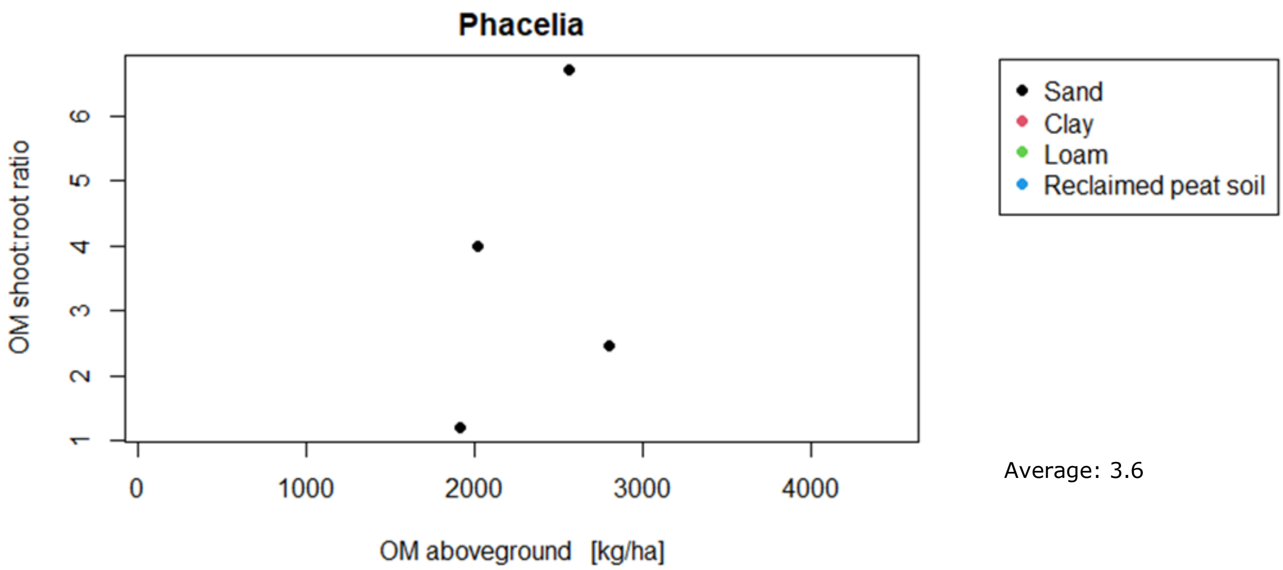


7.6.5 Italian ryegrass

```
lm(formula = shoot_root_ratio_om ~ 1, data = it_ryegr_data, weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-1.8619 -0.7697 -0.4421  0.6492  4.2446

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.3272     0.1483   8.952 1.45e-09 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.275 on 27 degrees of freedom
  (239 observations deleted due to missingness)
```

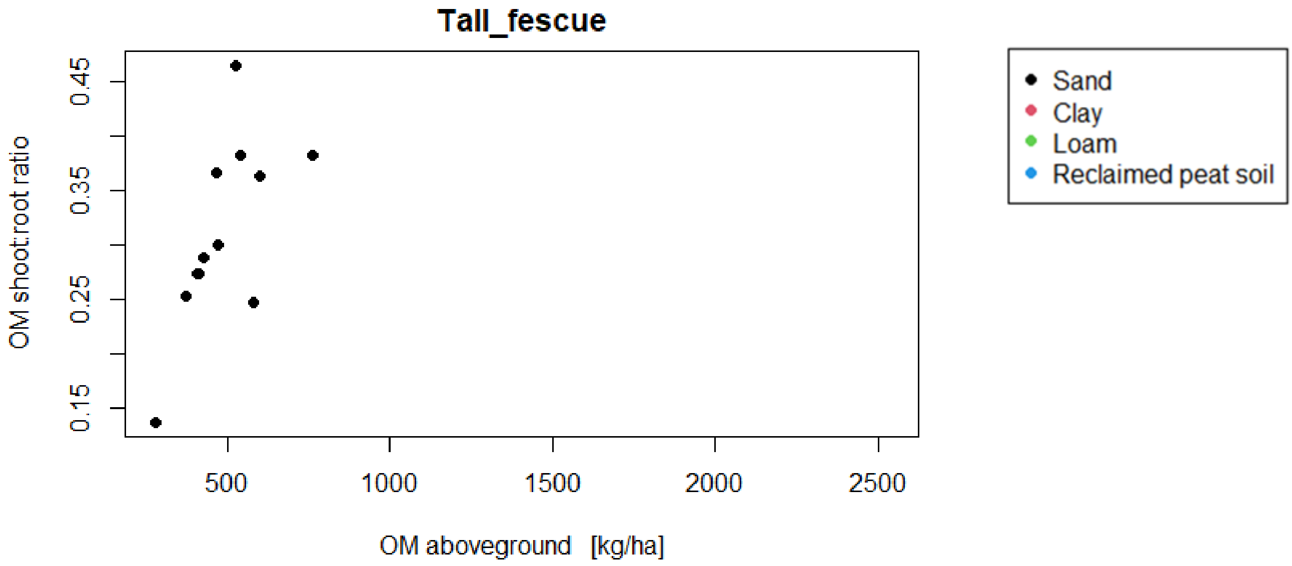


7.6.6 Phacelia



Average: 3.6

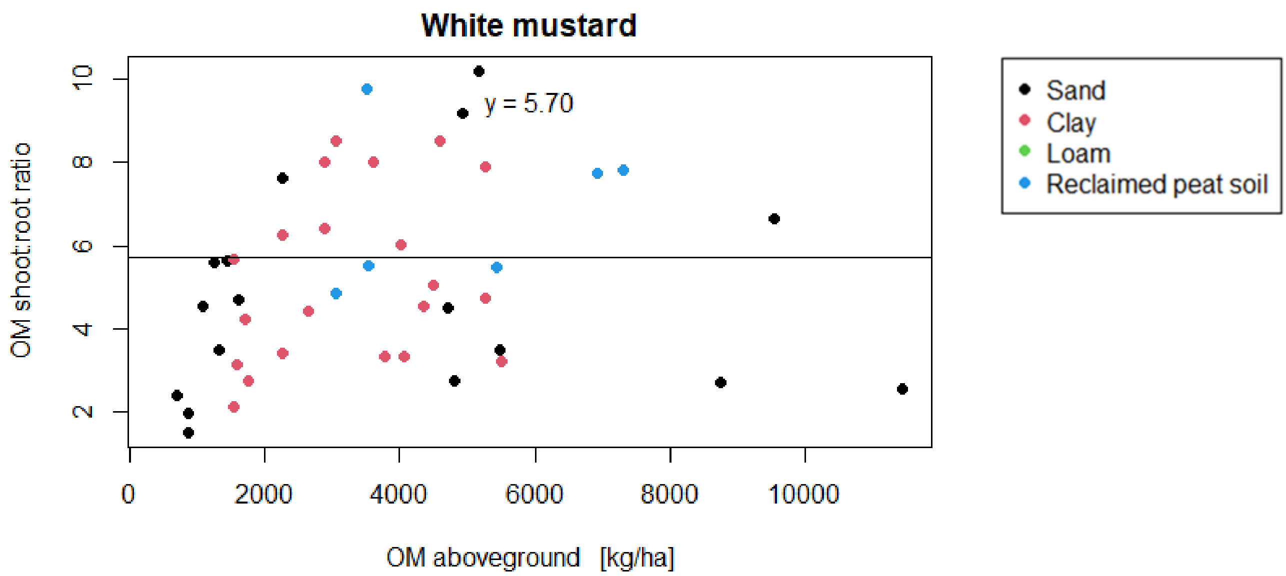
7.6.7 Tall fescue



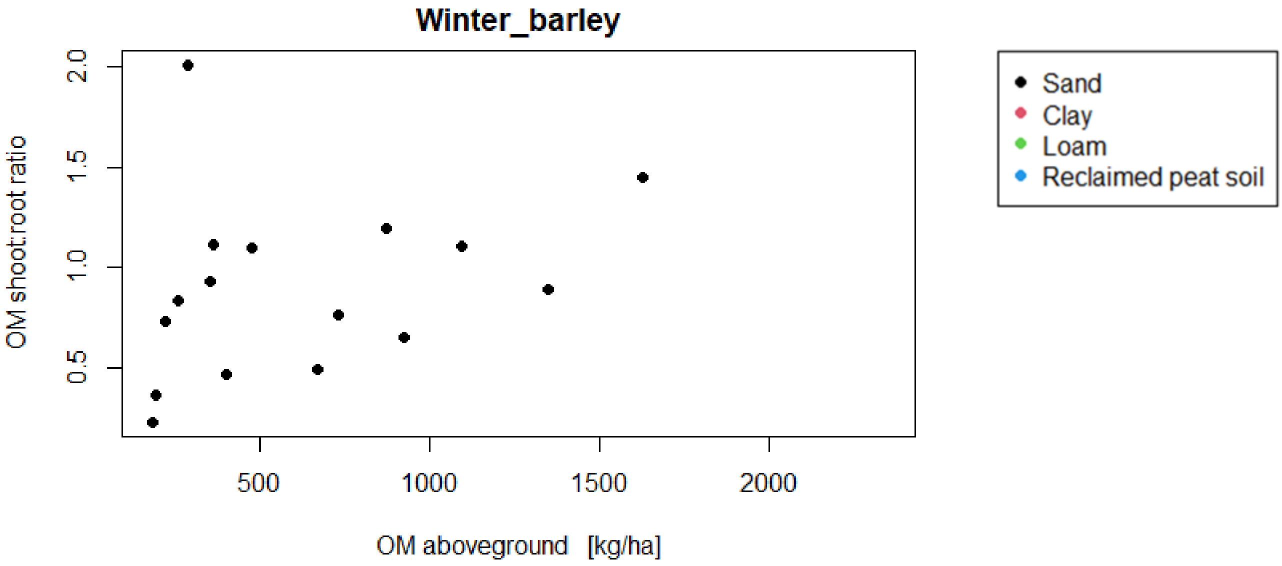
Average: 0.3

7.6.8 White mustard

```
lm(formula = shoot_root_ratio_om ~ 1, data = w_must_data, weights = weight_repetitions_above)

Weighted Residuals:
   Min     1Q Median     3Q    Max
-6.208 -2.361 -1.157  1.389  7.017

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   5.6989     0.3323   17.15   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.045 on 43 degrees of freedom
  (197 observations deleted due to missingness)
```



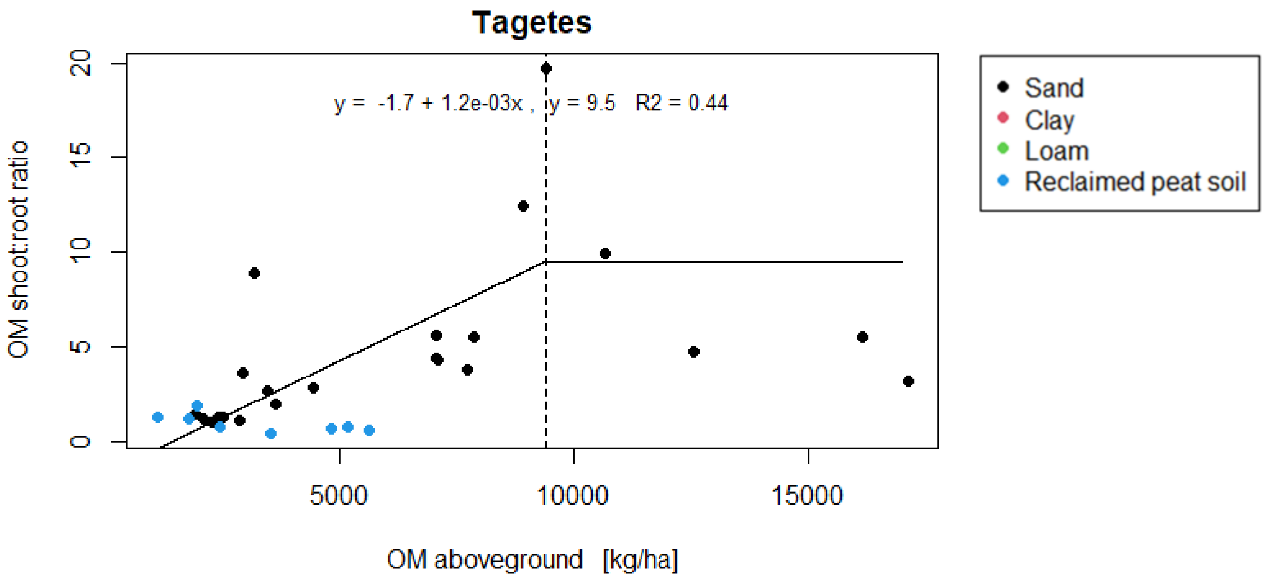
7.6.9 Winter barley



Average: 0.9

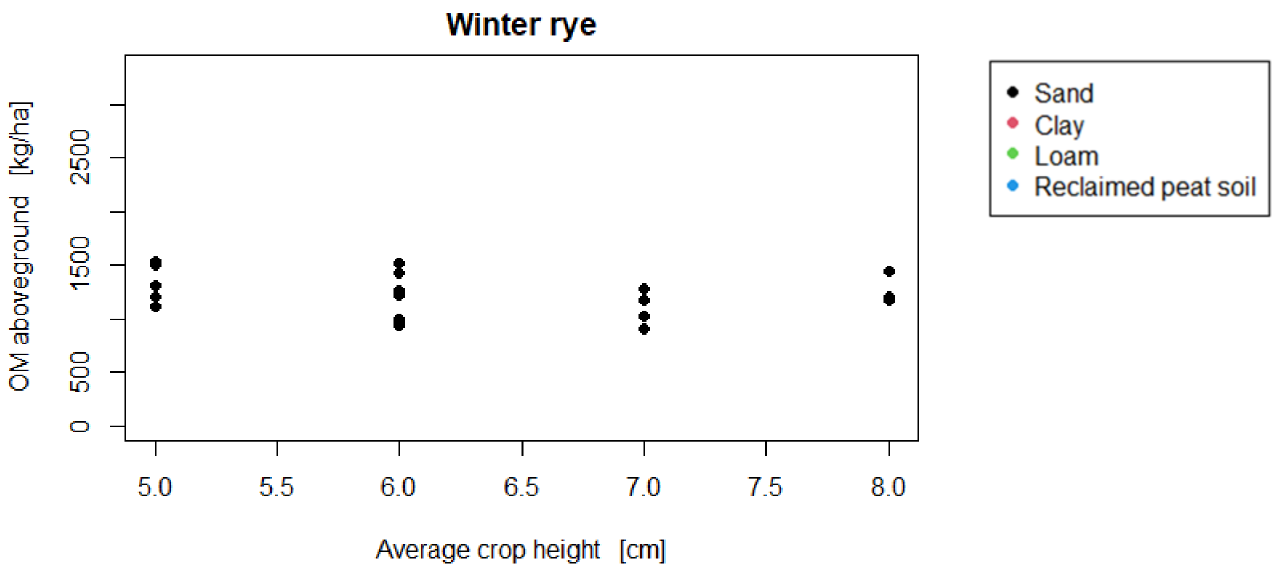
7.6.10 Tagetes

```
 ***Regression Model with Segmented Relationship(s)***
segmented.lm(obj = srom_tag_lm_basis)
Estimated Break-Point(s):
                              Est.   St.Err
psi1.om_aboveground_kg_ha 9407.309 1780.406
Meaningful coefficients of the linear terms:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)             -1.7053418  1.2299261  -1.387    0.177
om_aboveground_kg_ha     0.0011934  0.0002506   4.763 5.76e-05 ***
U1.om_aboveground_kg_ha -0.0019698  0.0006433  -3.062       NA

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.122 on 27 degrees of freedom
Multiple R-Squared: 0.4957,  Adjusted R-squared: 0.4396
Convergence attained in 1 iter. (rel. change 2.0058e-09)

$om_aboveground_kg_ha
             Est.     St.Err. t value   CI(95%).l  CI(95%).u
slope1  0.0011934 0.00025057  4.7628  0.00067929 0.00170750
slope2 -0.0007764 0.00059251 -1.3104 -0.00199210 0.00043932

Davies' test for a change in the slope
data:  formula = shoot_root_ratio_om ~ om_aboveground_kg_ha ,   method = lm
model = gaussian , link = identity
segmented variable = om_aboveground_kg_ha
'best' at = 9783.2, n.points = 10, p-value = 0.006339
alternative hypothesis: two.sided
```



7.7 OM aboveground vs. crop height

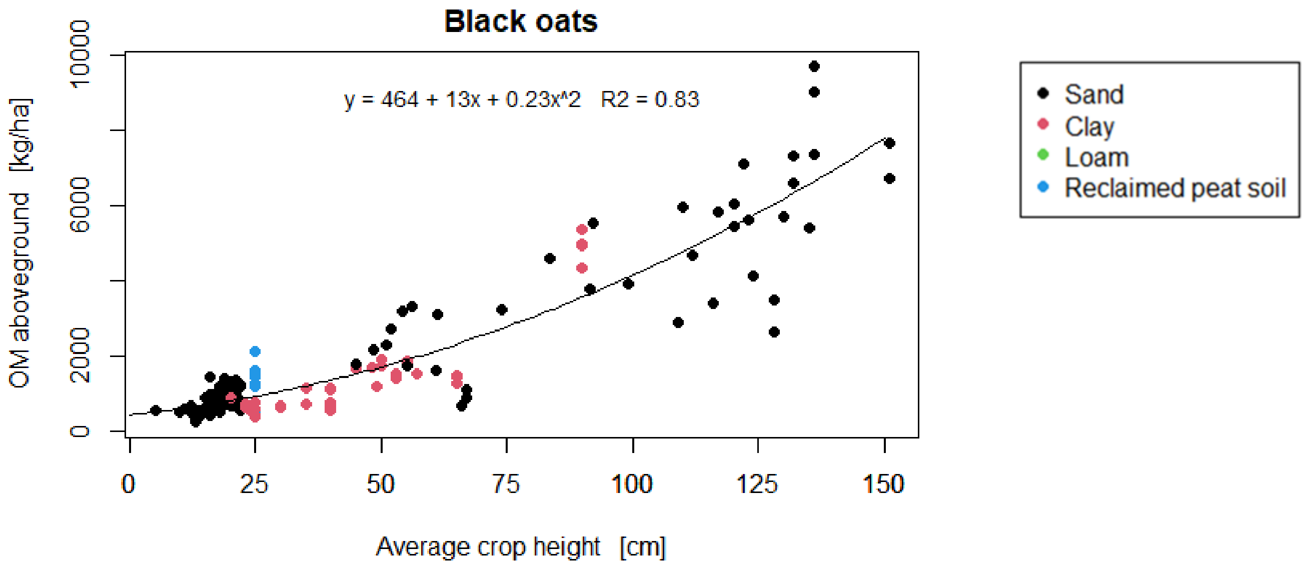
7.7.1 Winter rye



7.7.2 Black oats

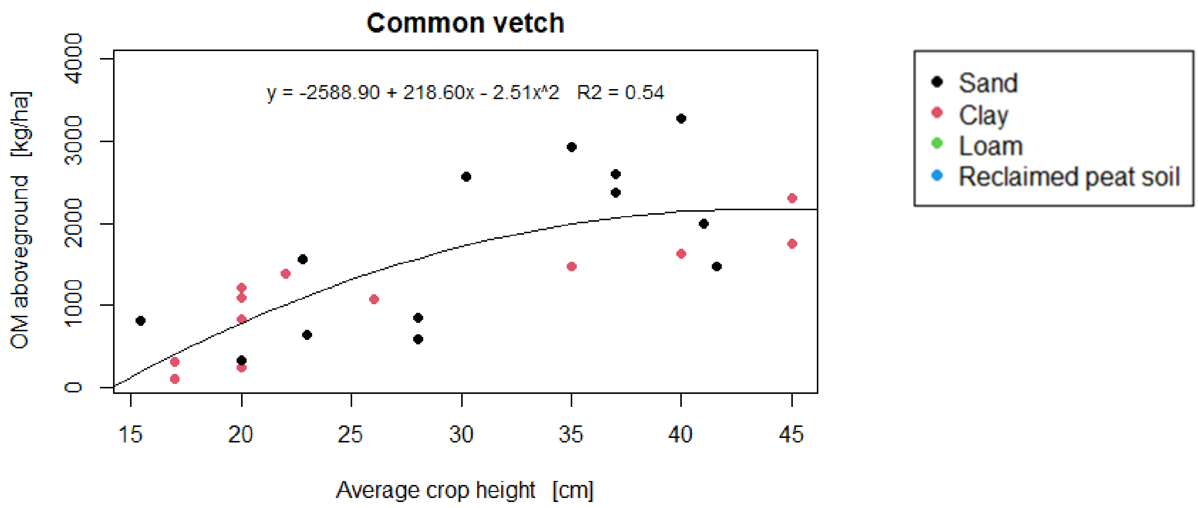
```
lm(formula = om_aboveground_kg_ha ~ average_crop_height_cm +
    h2, data = b_oats_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-3394.8  -364.2   -28.4   339.5  3067.2

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            464.35358  206.17656   2.252    0.026 *
average_crop_height_cm  13.45898    8.18767   1.644    0.103
h2                       0.23481    0.05592   4.199 4.92e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 841.3 on 131 degrees of freedom
```

```
  (242 observations deleted due to missingness)
Multiple R-squared:  0.8362, Adjusted R-squared:  0.8337
F-statistic: 334.5 on 2 and 131 DF,  p-value: < 2.2e-16
```



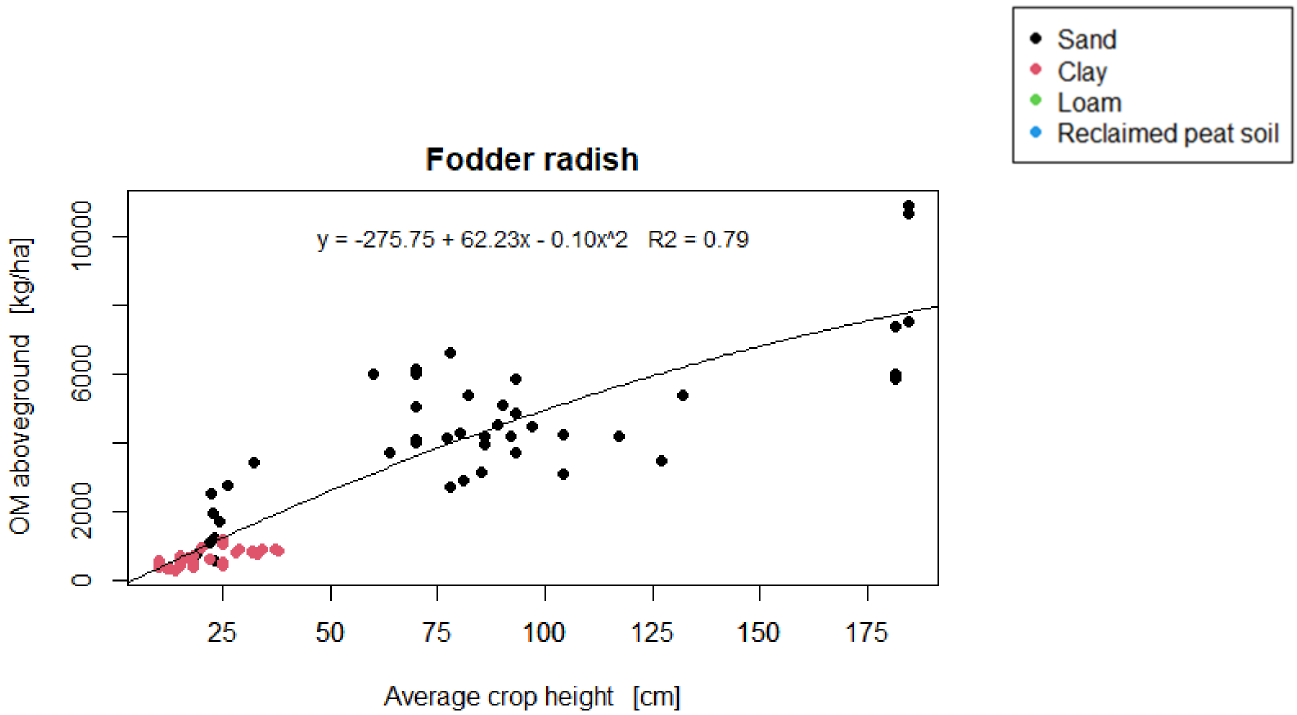
7.7.3 Common vetch

```
lm(formula = om_aboveground_kg_ha ~ average_crop_height_cm +
    h2, data = c_vetch_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-974.54 -466.66  -87.12  440.48 1131.24

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            -2588.902   1525.720  -1.697   0.1038
average_crop_height_cm   218.591    109.440   1.997   0.0583 .
h2                        -2.508      1.799  -1.394   0.1773

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 600.1 on 22 degrees of freedom
  (189 observations deleted due to missingness)
Multiple R-squared:  0.5794, Adjusted R-squared:  0.5411
F-statistic: 15.15 on 2 and 22 DF,  p-value: 7.292e-05
```

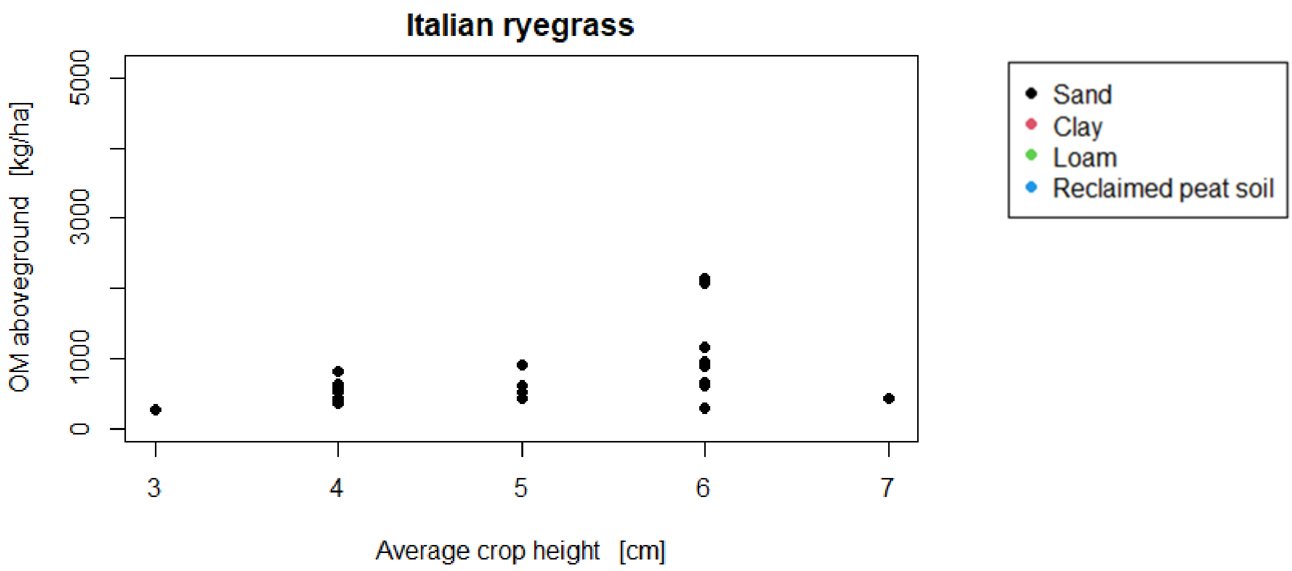


7.7.4 Fodder radish

```
lm(formula = om_aboveground_kg_ha ~ average_crop_height_cm +
    h2, data = f_radish_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-2537.8  -648.6  -130.8   214.3  3126.1

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)            -275.74687  300.27745  -0.918   0.3615
average_crop_height_cm   62.25516    9.00795   6.911 1.61e-09 ***
h2                       -0.10047    0.04894  -2.053   0.0437 *

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1148 on 72 degrees of freedom
  (217 observations deleted due to missingness)
Multiple R-squared:  0.7951, Adjusted R-squared:  0.7894
F-statistic: 139.7 on 2 and 72 DF,  p-value: < 2.2e-16
```

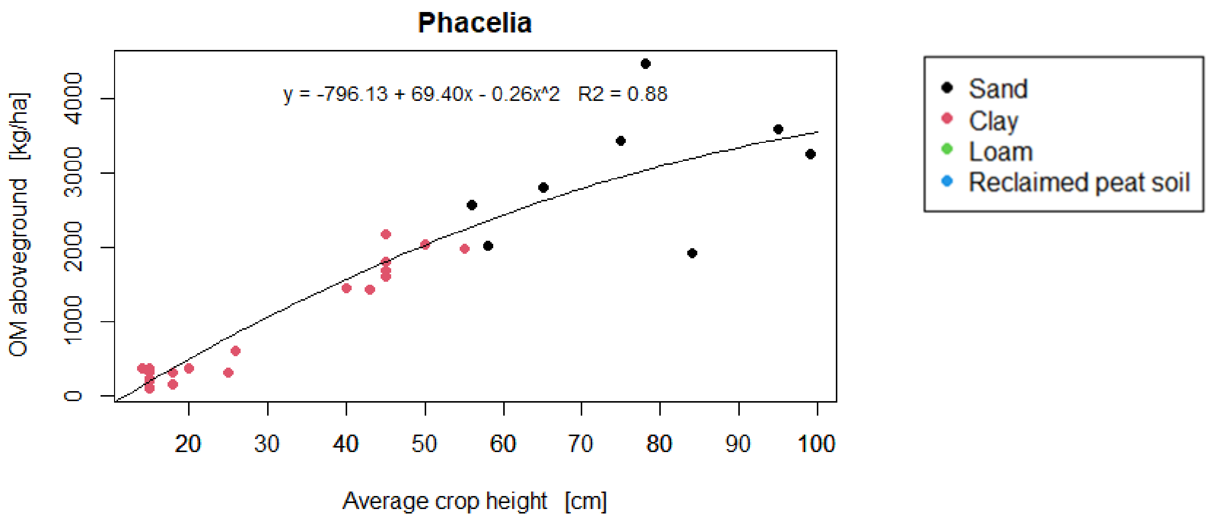


7.7.5 Italian ryegrass

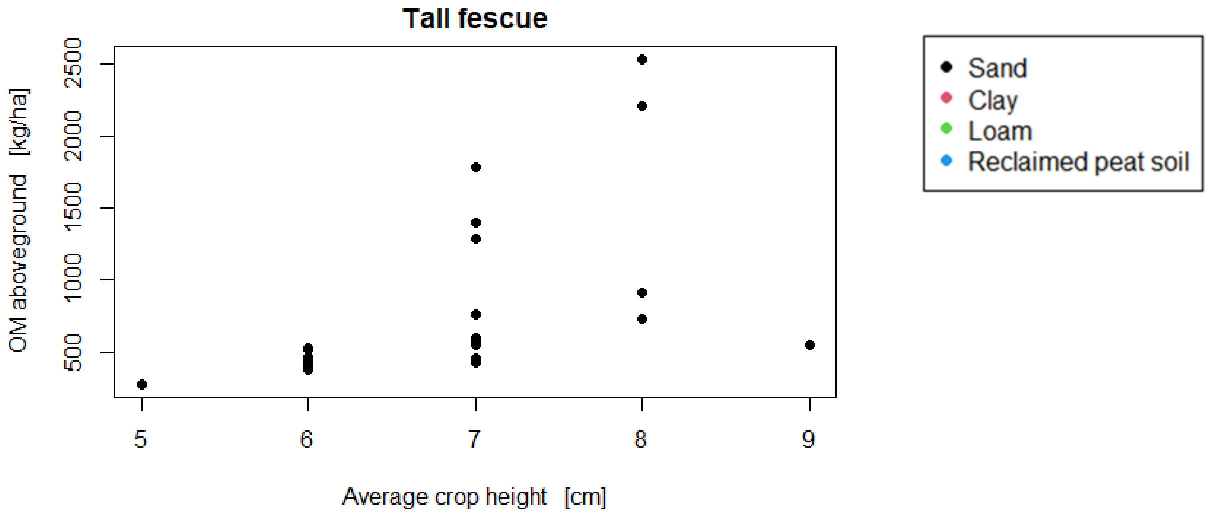


7.7.6 Phacelia

```
lm(formula = om_aboveground_kg_ha ~ average_crop_height_cm +
    h2, data = phac_data, weights = weight_repetitions_above)
Residuals:
     Min       1Q   Median       3Q      Max
-1273.52  -198.14     3.58   167.66  1439.30
Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            -796.1308   237.9548  -3.346  0.00228 **
average_crop_height_cm   69.3975    12.0485   5.760 3.08e-06 ***
h2                       -0.2610     0.1188  -2.197  0.03616 *
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 421.1 on 29 degrees of freedom
  (151 observations deleted due to missingness)
Multiple R-squared:  0.8904, Adjusted R-squared:  0.8828
F-statistic: 117.8 on 2 and 29 DF,  p-value: 1.194e-14
```

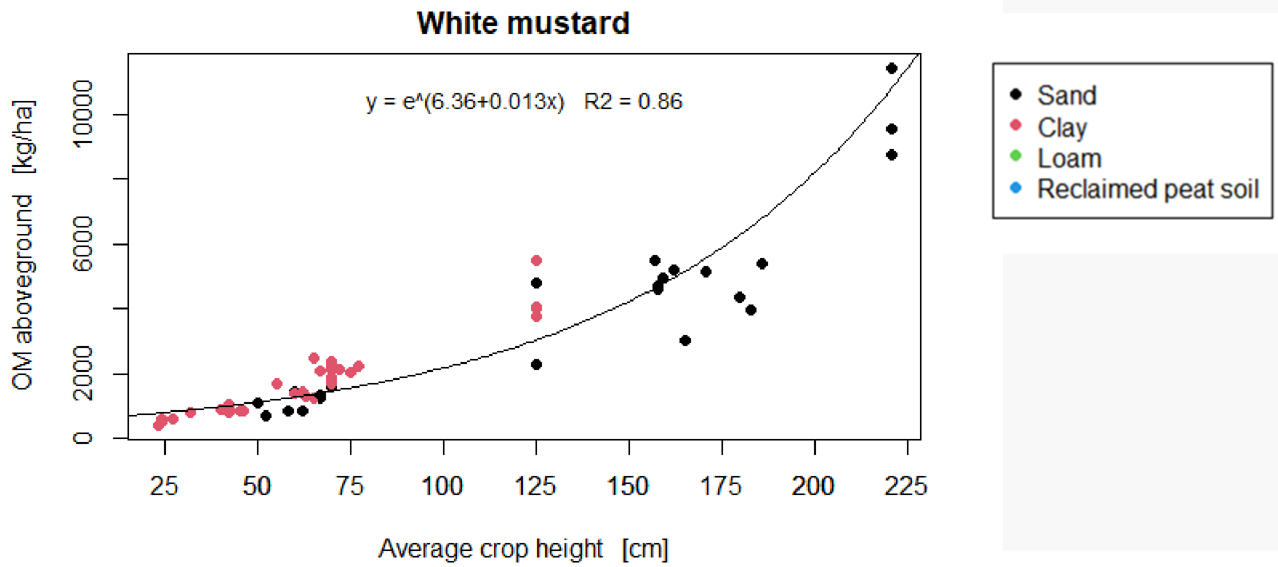


7.7.7 Tall fescue



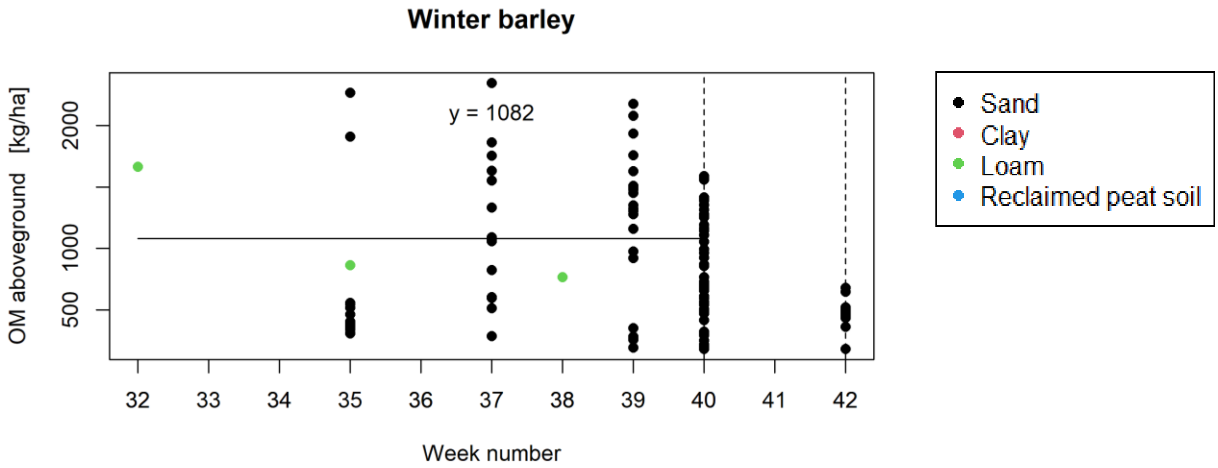
7.7.8 White mustard

```
Call:
lm(formula = log(om_aboveground_kg_ha) ~ average_crop_height_cm,
    data = w_must_data, weights = weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.61897 -0.22537 -0.01689  0.23712  0.59546 

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)           6.3583407  0.0793642   80.12   <2e-16 ***
average_crop_height_cm 0.0132661  0.0007342   18.07   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3046 on 53 degrees of freedom
  (186 observations deleted due to missingness)
Multiple R-squared:  0.8603, Adjusted R-squared:  0.8577 
F-statistic: 326.5 on 1 and 53 DF,  p-value: < 2.2e-16
```

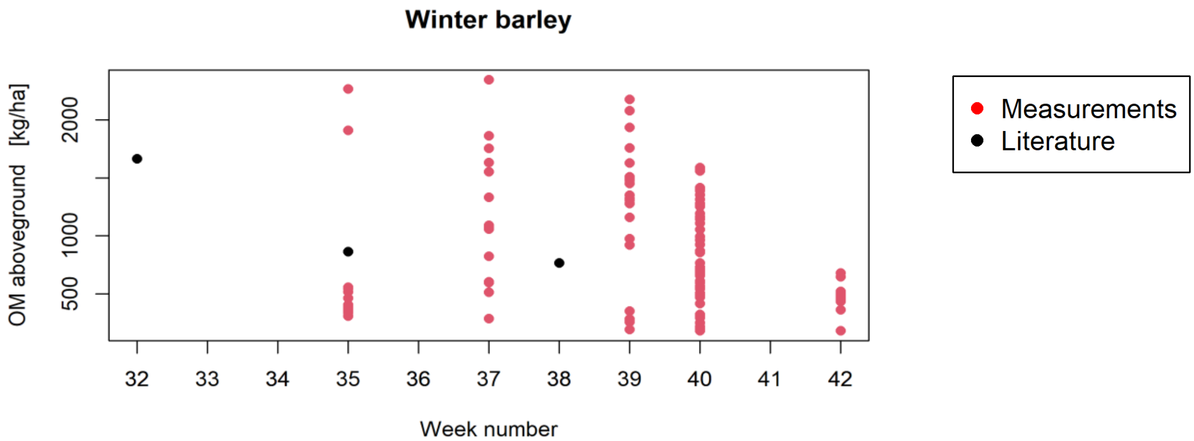


7.7.9 Winter barley

```
Call:
lm(formula = om_aboveground_kg_ha ~ 1, data = w_barl_data[w_barl_data$week number <
    40, ], weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-1850.6  -683.8   -23.5   428.7  3397.3

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  1082.37      67.88   15.95   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 836.8 on 52 degrees of freedom
  (8 observations deleted due to missingness)
```

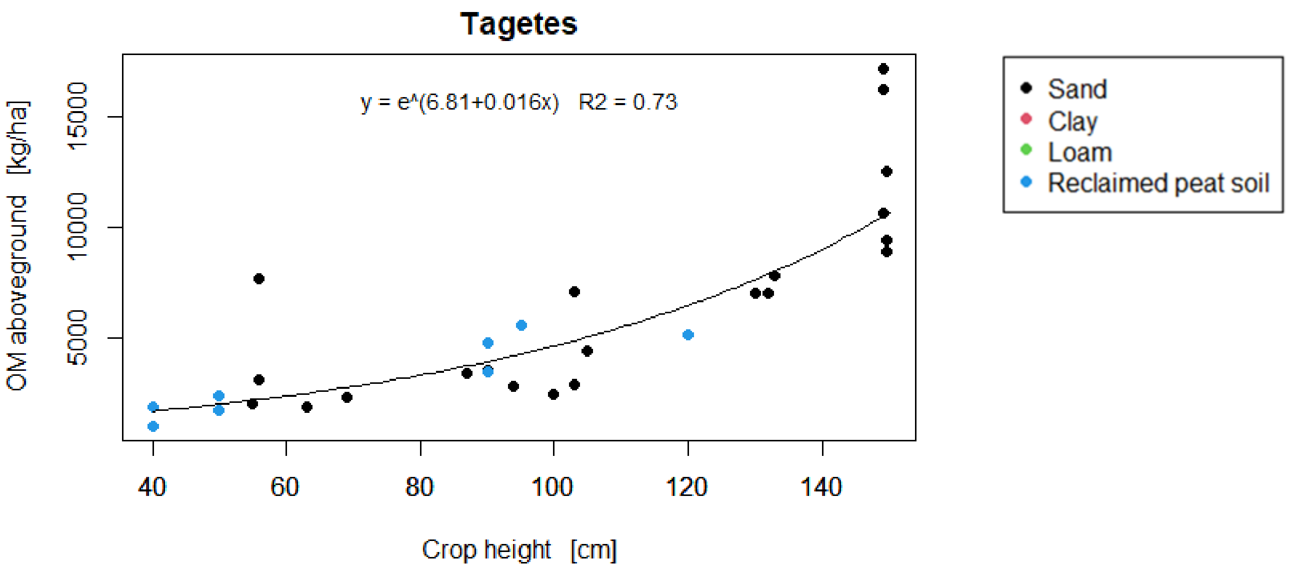


Week number < 40: 1082.37 kg OM/ha
Week number = 40: 747.7194 kg OM/ha
Week number = 42: 475.47 kg OM/ha



7.7.10 Tagetes

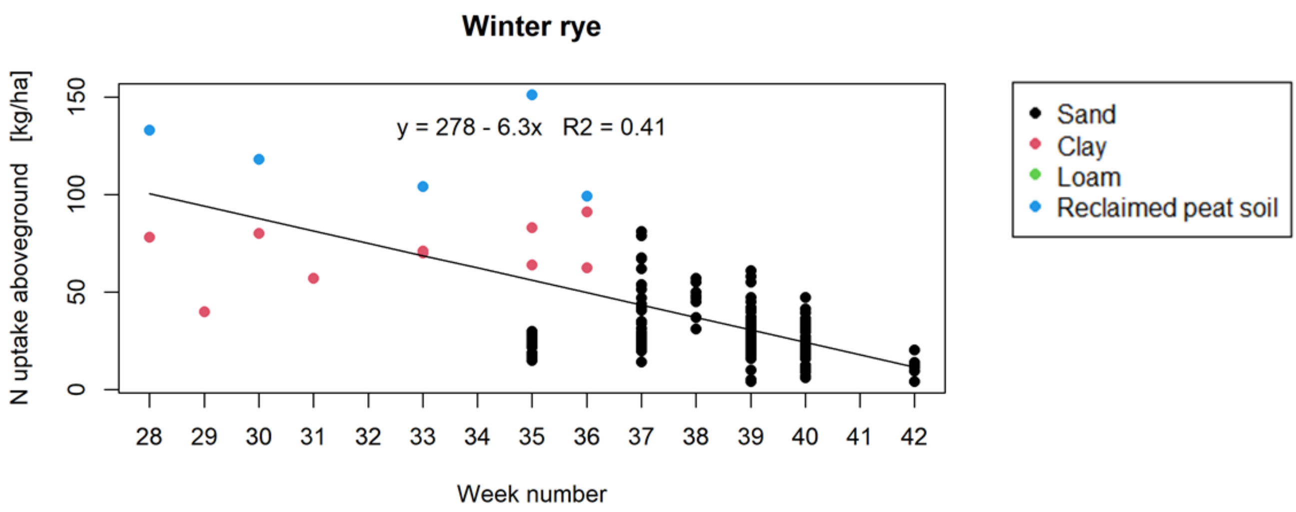
```
lm(formula = log(om_aboveground_kg_ha) ~ average_crop_height_cm,
    data = tag_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-0.6392 -0.1569 -0.1000  0.1772  1.2104

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            6.817666   0.195309  34.907  < 2e-16 ***
average_crop_height_cm 0.016495   0.001882   8.764 2.22e-09 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3694 on 27 degrees of freedom
  (20 observations deleted due to missingness)
Multiple R-squared:  0.7399, Adjusted R-squared:  0.7302
F-statistic:  76.8 on 1 and 27 DF,  p-value: 2.225e-09
```



7.8 N uptake aboveground vs. week number

7.8.1 Winter rye

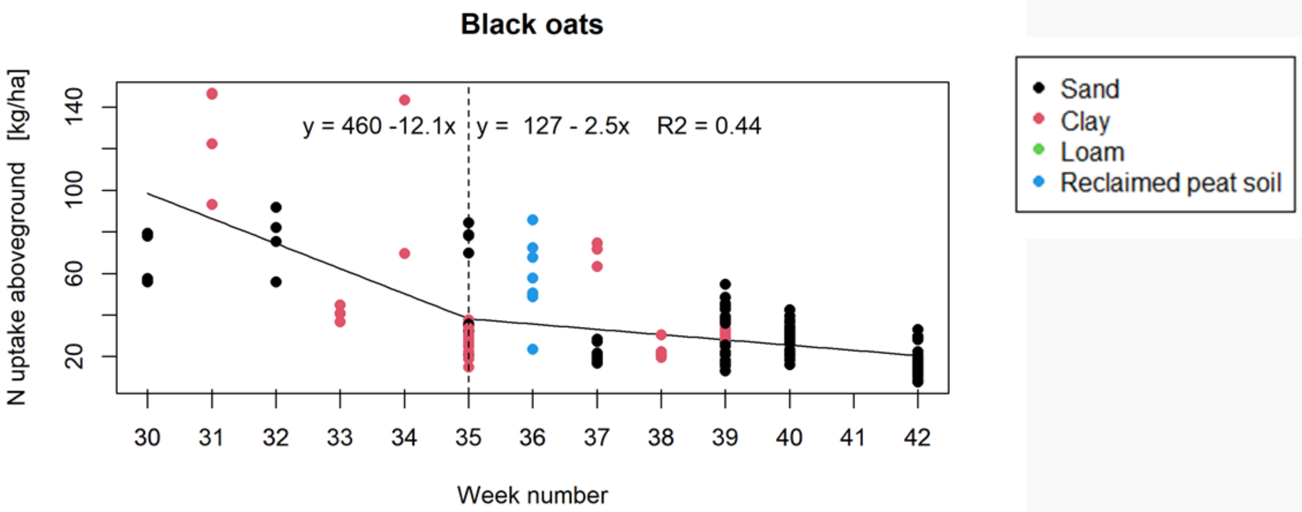
```
lm(formula = n_uptake_kg_ha ~ week number, data = w_rye_data,
    weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-93.633 -15.231  -1.590   6.611 164.602

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  278.169     20.971   13.26   <2e-16 ***
week number   -6.349      0.552  -11.50   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 27.05 on 185 degrees of freedom
  (155 observations deleted due to missingness)
Multiple R-squared:  0.4169, Adjusted R-squared:  0.4137
F-statistic: 132.3 on 1 and 185 DF,  p-value: < 2.2e-16
```



7.8.2 Black oats

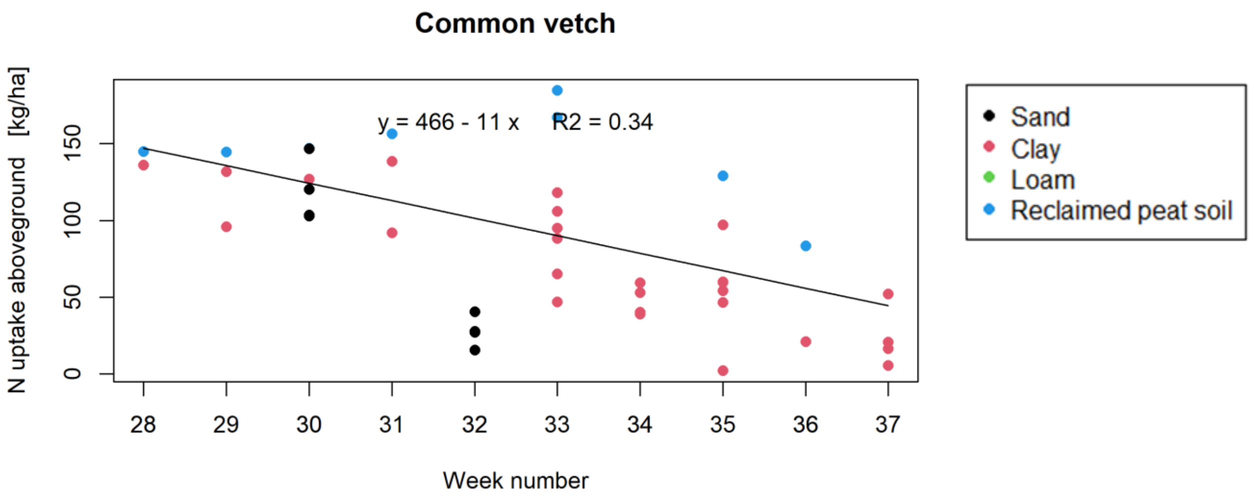
```
Estimated Break-Point(s):
                 Est. St.Err
psi1.week number   35  0.564

Meaningful coefficients of the linear terms:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    460.191     49.153   9.362  < 2e-16 ***
week number    -12.057      1.441  -8.365 2.09e-14 ***
U1.week number   9.530      1.712   5.568       NA

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 18.44 on 170 degrees of freedom
Multiple R-Squared: 0.4513,  Adjusted R-squared: 0.4417

Convergence attained in 4 iter. (rel. change -1.0399e-06)

$week number
           Est. St.Err. t value CI(95%).l CI(95%).u
slope1 -12.057 1.44130 -8.3654  -14.9020  -9.21190
slope2  -2.527 0.92316 -2.7373   -4.3493  -0.70465

 Davies' test for a change in the slope
data:  formula = n_uptake_kg_ha ~ week number ,   method = lm
model = gaussian , link = identity
```

```
segmented variable = week number
'best' at = 35.333, n.points = 8, p-value = 1.13e-05
alternative hypothesis:  two.sided
```



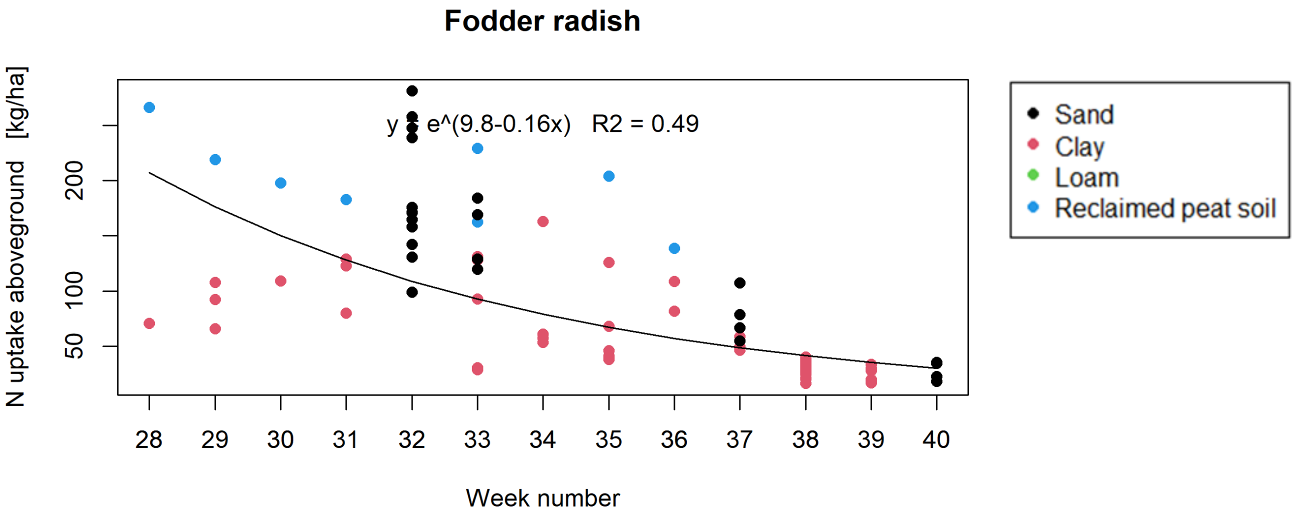
7.8.3 Common vetch

```
lm(formula = n_uptake_kg_ha ~ week_number, data = c_vetch_data,
    weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-113.05  -37.26  -12.95   18.94  163.74

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  466.389     77.734   6.000 4.33e-07 ***
week_number  -11.403      2.396  -4.759 2.43e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 56.81 on 41 degrees of freedom
  (175 observations deleted due to missingness)
Multiple R-squared:  0.3558, Adjusted R-squared:  0.3401
F-statistic: 22.65 on 1 and 41 DF,  p-value: 2.427e-05
```



7.8.4 Fodder radish

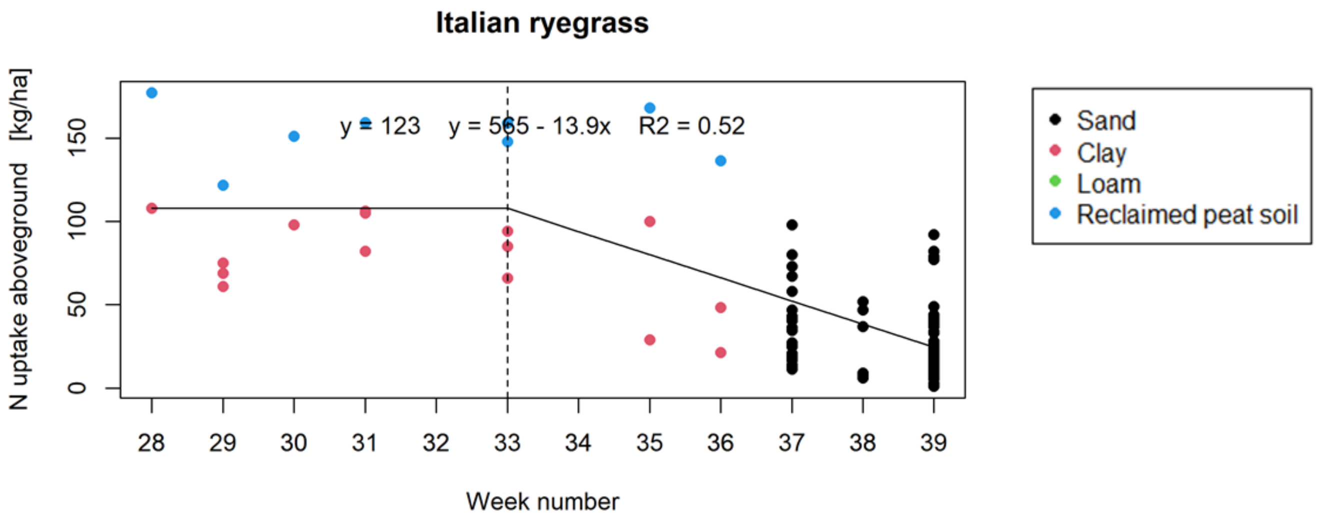
```
lm(formula = log(n_uptake_kg_ha) ~ week number, data = f_radish_data,
    weights = weight_repetitions_above)

Weighted Residuals:
     Min       1Q   Median       3Q      Max 
-1.85460 -0.48883 -0.07211  0.44225  1.92099 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  9.83103    0.59169  16.615  < 2e-16 ***
week number -0.16063    0.01733  -9.268 1.05e-14 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.688 on 89 degrees of freedom
  (205 observations deleted due to missingness)
Multiple R-squared:  0.4911, Adjusted R-squared:  0.4854 
F-statistic:  85.9 on 1 and 89 DF,  p-value: 1.046e-14
```



7.8.5 Italian ryegrass

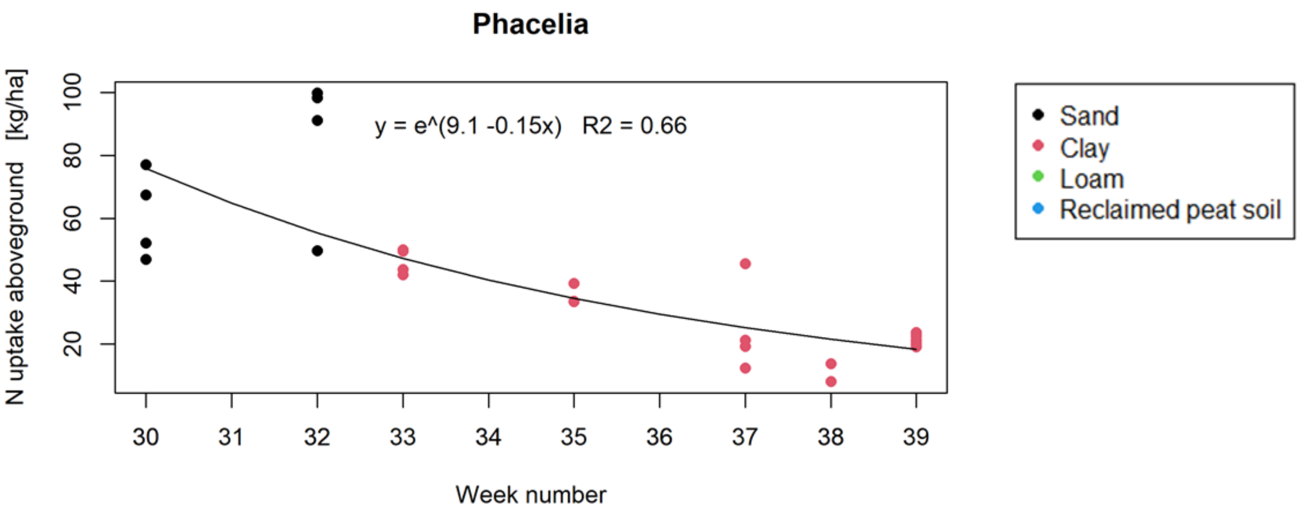
```
 ***Regression Model with Segmented Relationship(s)***
Call: 
segmented.lm(obj = nu_it_ryegr_lm, psi = 35)

Estimated Break-Point(s):
                   Est. St.Err
psi1.week number 32.986  1.994

Meaningful coefficients of the linear terms:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   122.5229   212.7354   0.576    0.566
week number    -0.4413     7.1659  -0.062    0.951
U1.week number -13.4205     7.3910  -1.816       NA

Residual standard error: 47.53 on 113 degrees of freedom
Multiple R-Squared: 0.5284,  Adjusted R-squared: 0.5159 

Convergence attained in 5 iter. (rel. change 0)

$week number
            Est. St.Err.   t value CI(95%).l CI(95%).u
slope1  -0.44133  7.1659 -0.061588   -14.638    13.756
slope2 -13.86200  1.8103 -7.657300   -17.448   -10.275
```

```
 Davies' test for a change in the slope
data:  formula = n_uptake_kg_ha ~ week number ,   method = lm
model = gaussian , link = identity
segmented variable = week number
'best' at = 32.889, n.points = 8, p-value = 0.03865
alternative hypothesis: two.sided
```



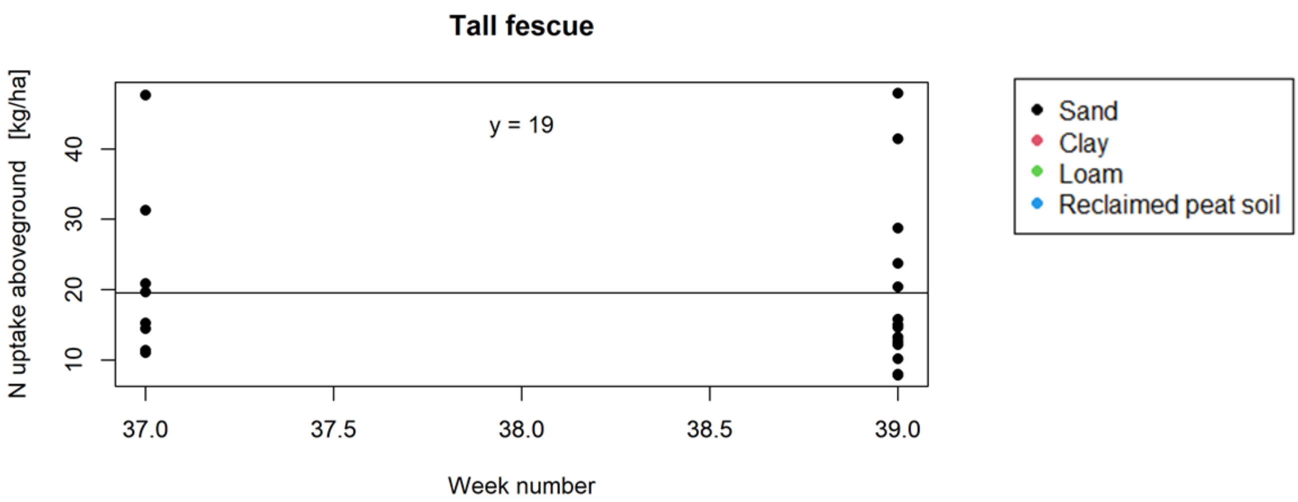
7.8.6 *Phacelia*

```
lm(formula = log(n_uptake_kg_ha) ~ week number, data = phac_data,
    weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-0.9953 -0.1187  0.0437  0.1849  0.5934

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  9.06378    0.73562  12.321 7.97e-13 ***
week number -0.15782    0.02081  -7.583 2.92e-08 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3681 on 28 degrees of freedom
  (157 observations deleted due to missingness)
Multiple R-squared:  0.6725, Adjusted R-squared:  0.6609
F-statistic: 57.51 on 1 and 28 DF,  p-value: 2.924e-08
```



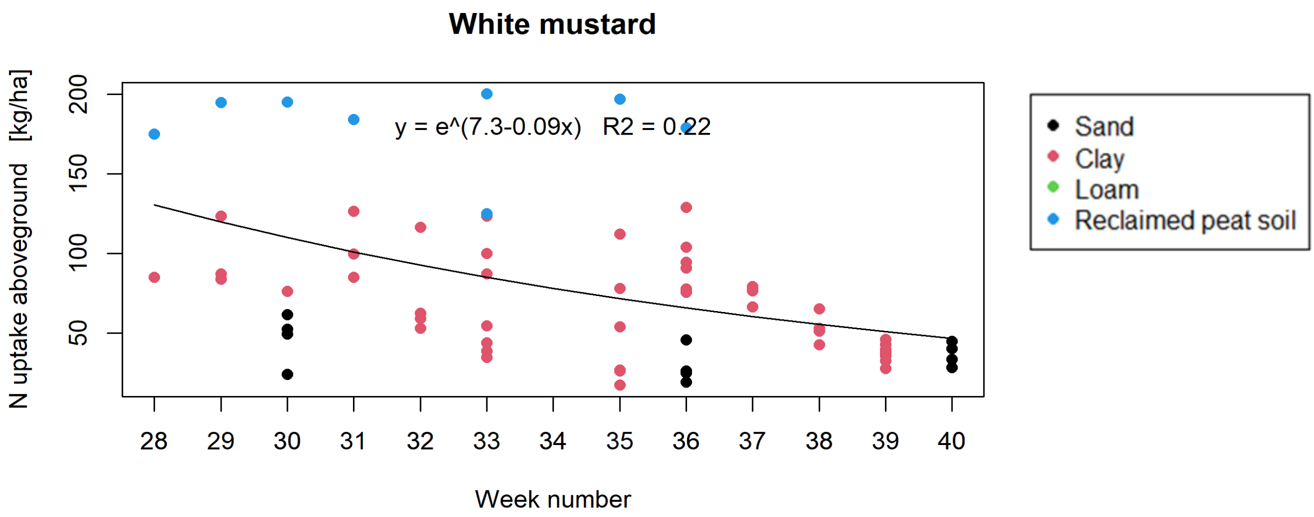
7.8.7 Tall fescue

```
Call:
lm(formula = n_uptake_kg_ha ~ 1, data = t_fesc_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-11.715  -7.290  -4.715   2.038  28.337

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   19.546      2.389   8.183  2.9e-08 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.7 on 23 degrees of freedom
  (155 observations deleted due to missingness)
```



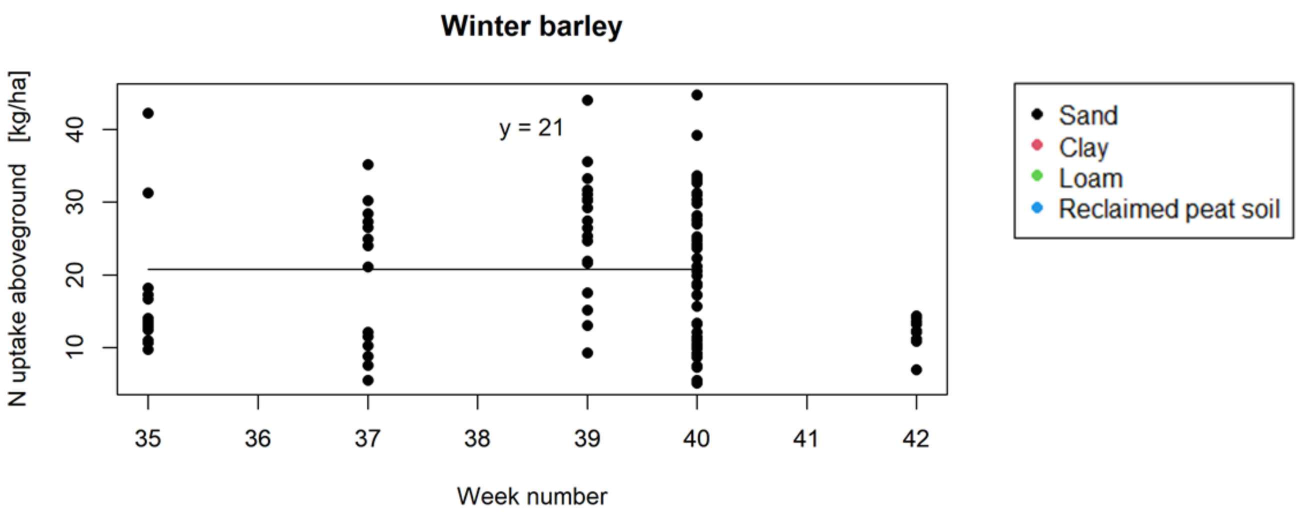
7.8.8 White mustard

```
Call:
lm(formula = log(n_uptake_kg_ha) ~ week_number, data = w_must_data,
    weights = weight_repetitions_above)

Weighted Residuals:
    Min      1Q  Median      3Q     Max
-1.5229 -0.5702 -0.1749  0.2643  1.7515

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   7.2681     0.6493  11.194  < 2e-16 ***
week_number  -0.0856     0.0193  -4.435 3.63e-05 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.6991 on 65 degrees of freedom
  (178 observations deleted due to missingness)
Multiple R-squared:  0.2323, Adjusted R-squared:  0.2205
F-statistic: 19.67 on 1 and 65 DF,  p-value: 3.627e-05
```



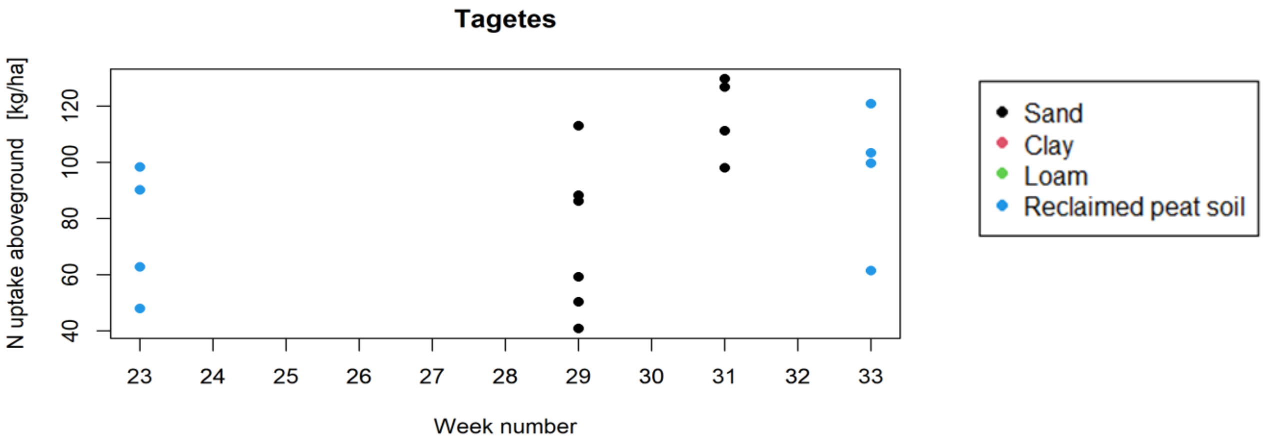
7.8.9 Winter barley

```
Call:
lm(formula = n_uptake_kg_ha ~ 1, data = w_barl_data[w_barl_data$week number <
    41, ], weights = weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-15.6699  -8.6206  -0.1914   7.4438  23.9679

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  20.7461     0.9527   21.78   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9.574 on 100 degrees of freedom
  (155 observations deleted due to missingness)
```



Average for week 42 = 12.1 kg N/ha

7.8.10 Tagetes

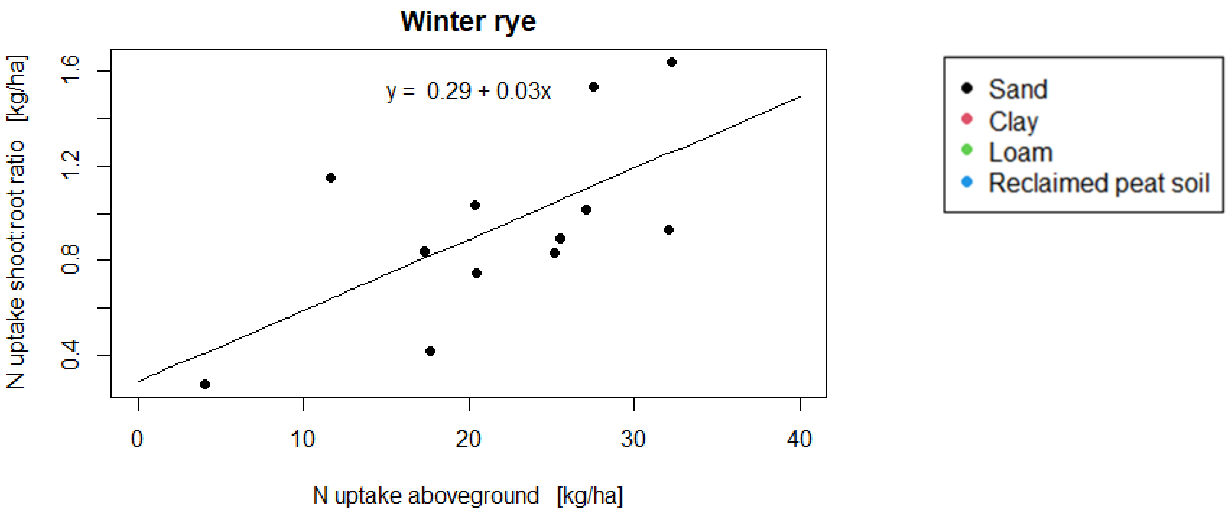


Average: 88.23 kg N/ha

7.9 Shoot:root N uptake ratio vs. N uptake

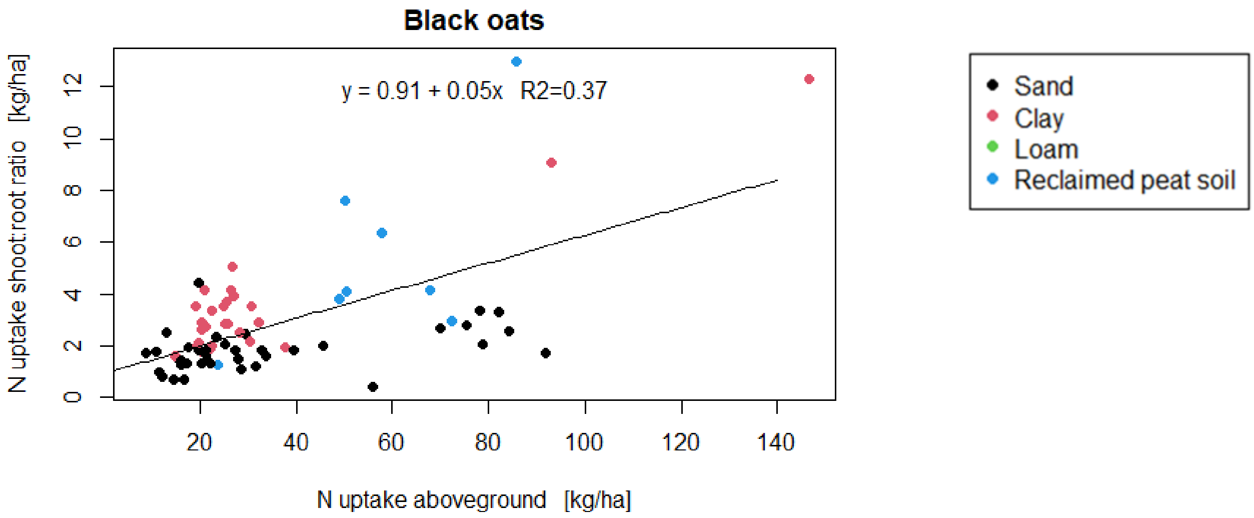
7.9.1 *Winter rye*

```
lm(formula = ((shoot_root_ratio_n_uptake)) ~ n_uptake_kg_ha,
     data = w_rye_data, weights = weight_repetitions_above)

Residuals:
     Min       1Q  Median      3Q     Max
-0.3977 -0.1740 -0.1078  0.1948  0.5083

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)     0.29119    0.26259   1.109   0.2934
n_uptake_kg_ha  0.02997    0.01134   2.644   0.0246 *

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.312 on 10 degrees of freedom
  (326 observations deleted due to missingness)
Multiple R-squared:  0.4114, Adjusted R-squared:  0.3525
F-statistic: 6.988 on 1 and 10 DF,  p-value: 0.02458
```

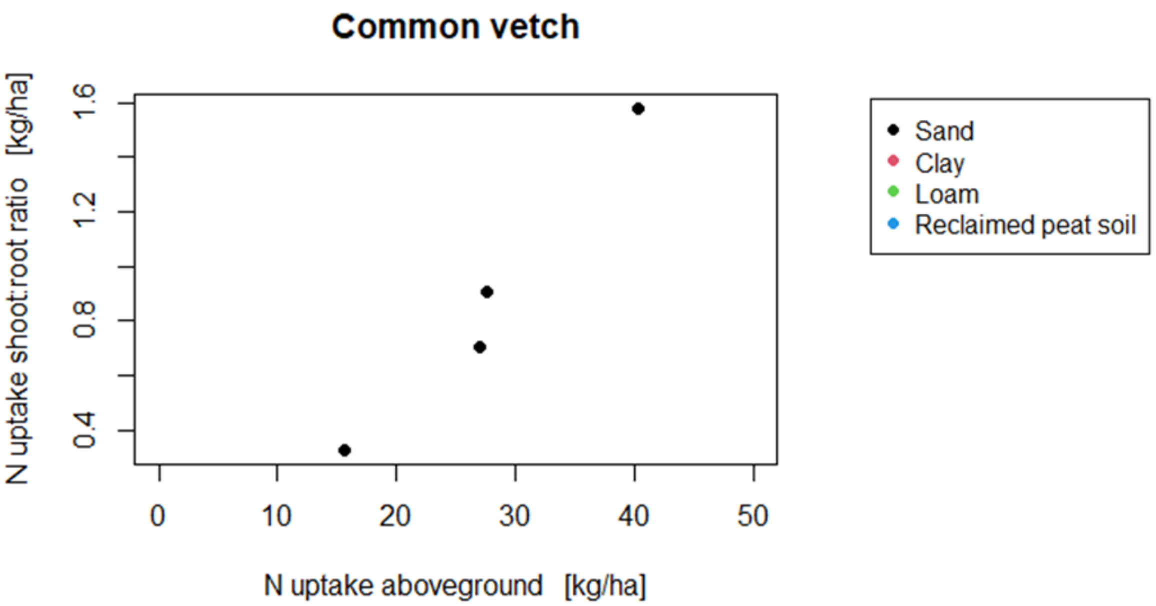


7.9.2 Black oats

```
lm(formula = shoot_root_ratio_n_uptake ~ n_uptake_kg_ha, data = b_oats_data,
    weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-4.0992 -0.9129 -0.2323  0.6298  7.4854

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.919131   0.355609   2.585   0.0118 *
n_uptake_kg_ha 0.053449   0.008098   6.600 6.64e-09 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.769 on 70 degrees of freedom
  (308 observations deleted due to missingness)
Multiple R-squared:  0.3836, Adjusted R-squared:  0.3748
F-statistic: 43.56 on 1 and 70 DF,  p-value: 6.637e-09
```



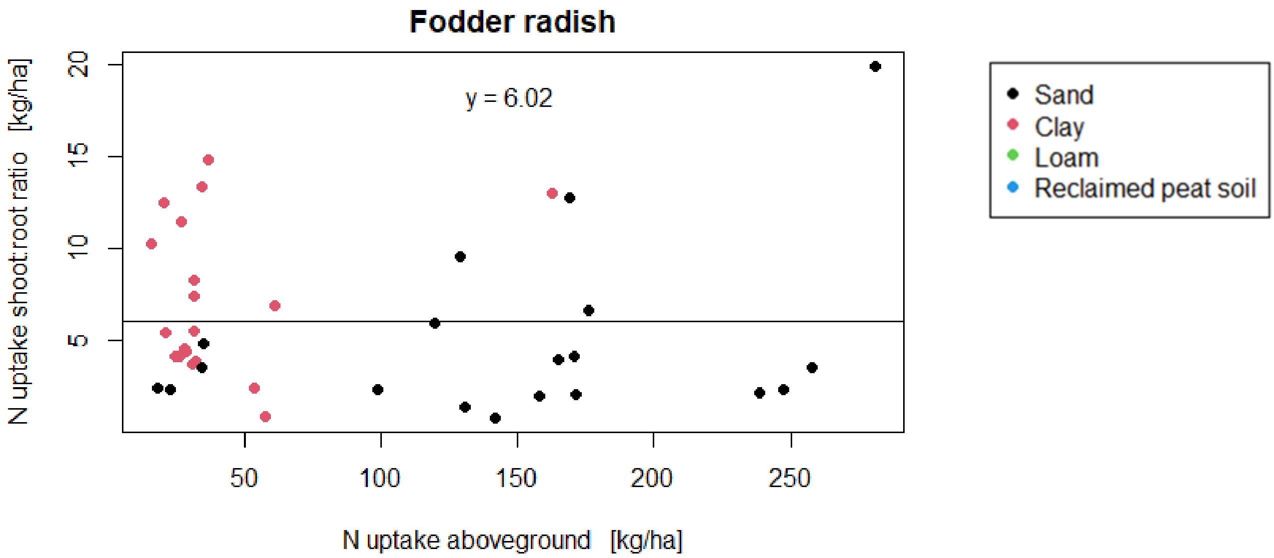
7.9.3 Common vetch



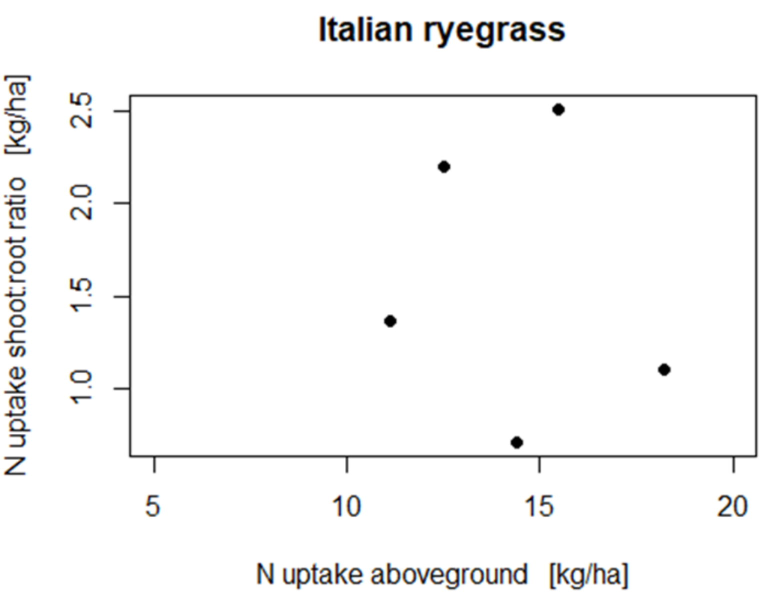
Average: 0.88

7.9.4 Fodder radish

```
Call:
lm(formula = shoot_root_ratio_n_uptake ~ 1, data = f_radish_data,
    weights = weight_repetitions_above)

Residuals:
   Min     1Q Median     3Q    Max
-5.250 -3.633 -1.772  1.990 13.904

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   6.0169     0.7379   8.154 8.74e-10 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 4.549 on 37 degrees of freedom
  (258 observations deleted due to missingness)
```

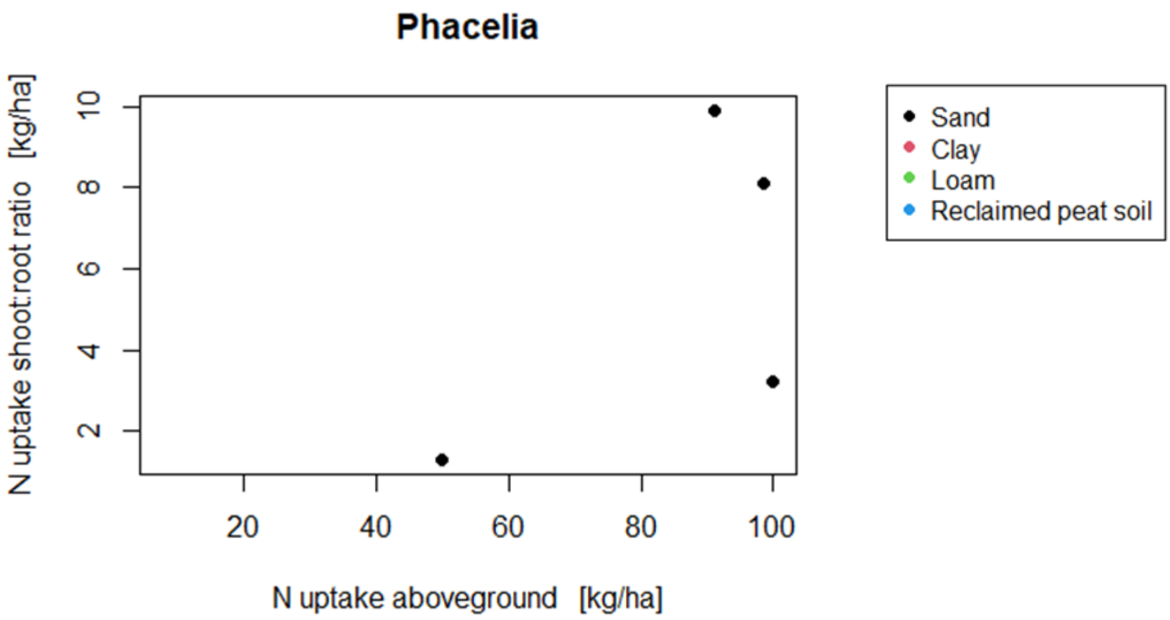


7.9.5 Italian ryegrass



Average: 1.58

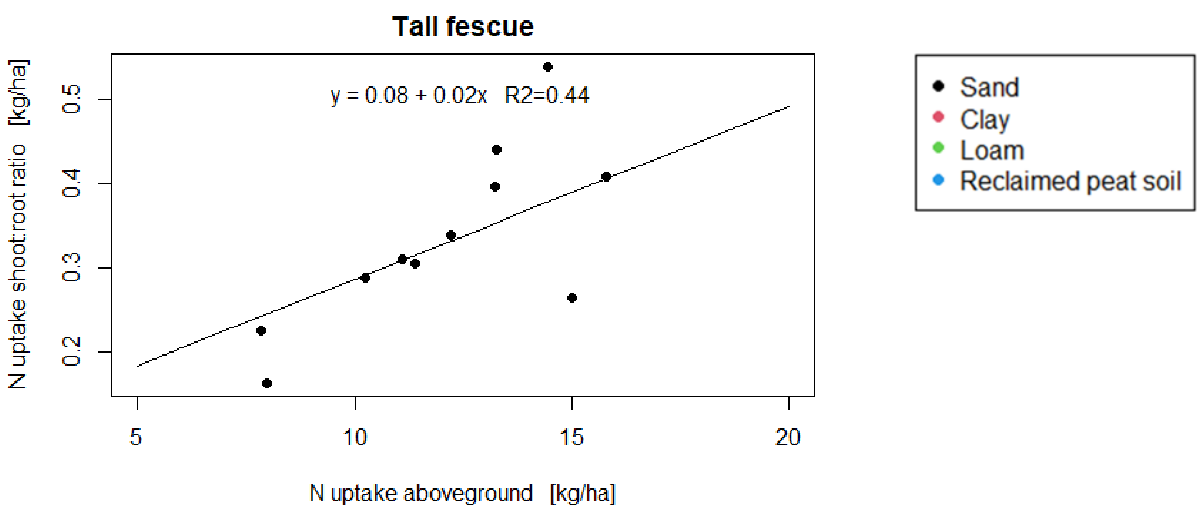
7.9.6 Phacelia



Average: 5.63

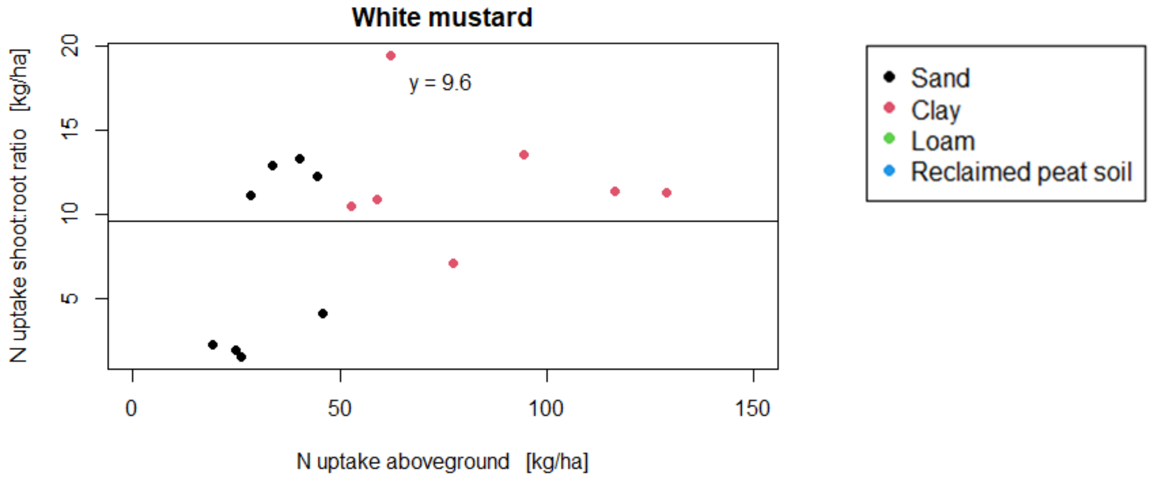
7.9.7 Tall fescue

```
Call:
lm(formula = (shoot_root_ratio_n_uptake) ~ n_uptake_kg_ha, data = t_fesc_data, weights =
weight_repetitions_above)
Residuals:
      Min        1Q    Median        3Q       Max
-0.125917 -0.028591 -0.001304  0.015743  0.161359
Coefficients:
               Estimate Std. Error t value Pr(>|t|)
(Intercept)    0.081418   0.088173   0.923   0.3775
n_uptake_kg_ha 0.020539   0.006663   3.082   0.0116 *

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.0794 on 10 degrees of freedom
  (167 observations deleted due to missingness)
Multiple R-squared:  0.4872,	Adjusted R-squared:  0.4359
F-statistic: 9.502 on 1 and 10 DF,  p-value: 0.01159
```

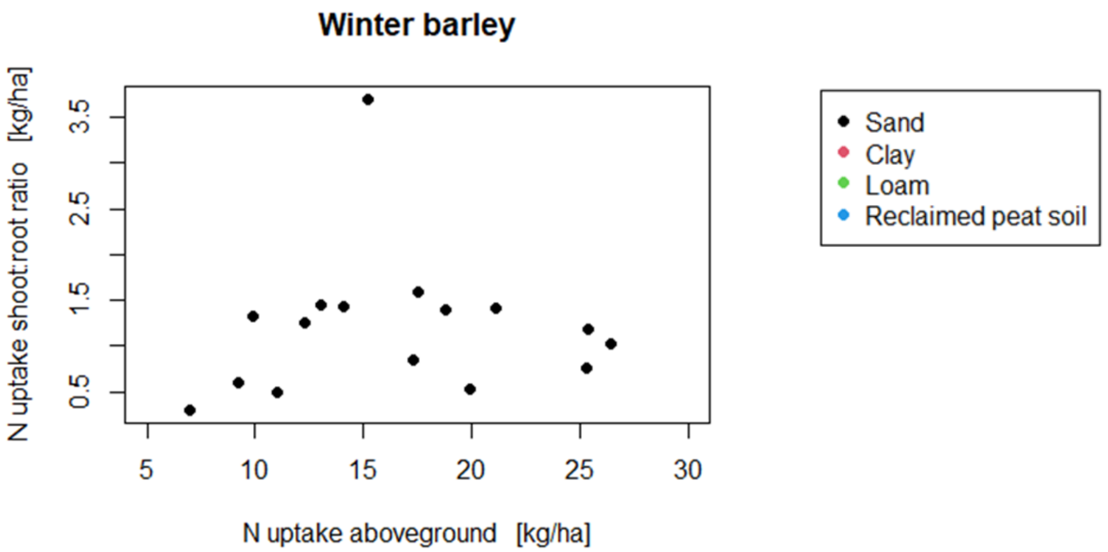


7.9.8 White mustard

```
Call:
lm(formula = (shoot_root_ratio_n_uptake) ~ 1, data = w_must_data,
    weights = weight_repetitions_above)

Residuals:
   Min     1Q Median     3Q    Max
-8.015 -3.978  1.529  2.995  9.902

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)    9.582      1.328   7.218 4.44e-06 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.141 on 14 degrees of freedom
  (230 observations deleted due to missingness)
```



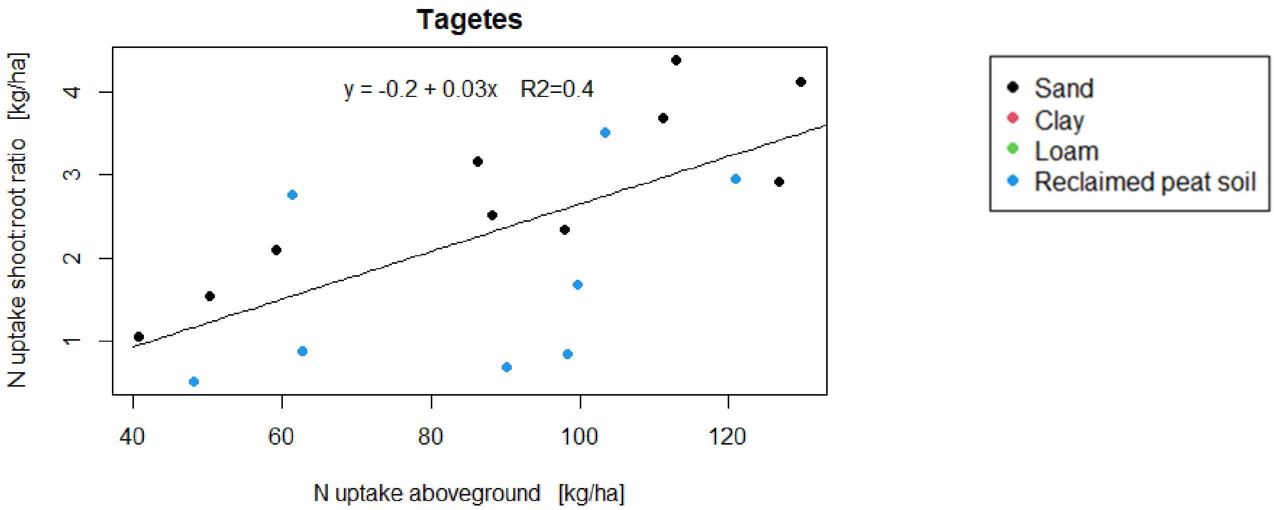
7.9.9 Winter barley



Average: 1.21

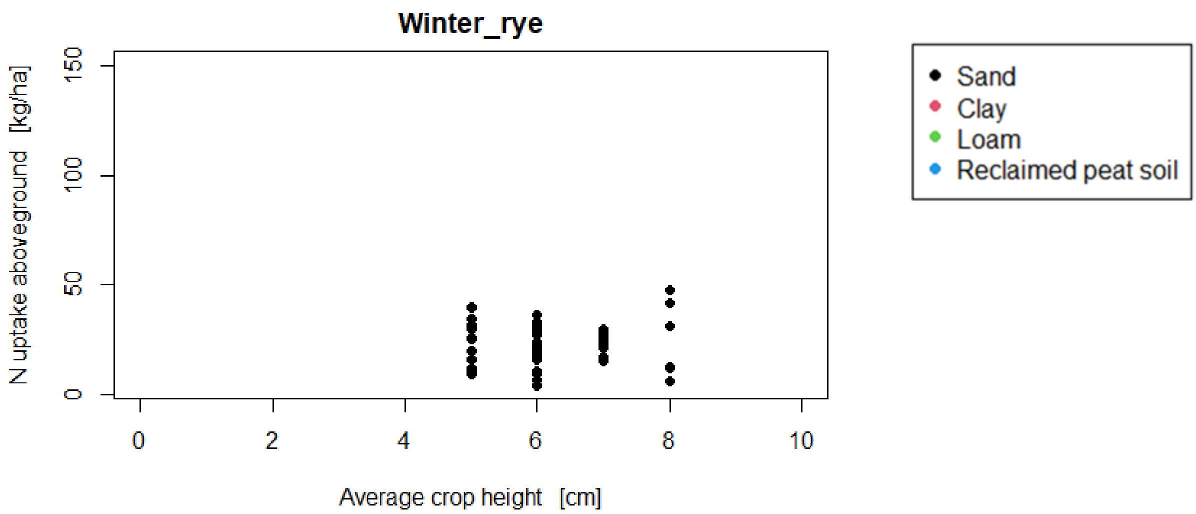
7.9.10 Tagetes

```
lm(formula = (shoot_root_ratio_n_uptake) ~ n_uptake_kg_ha, data = tag_data,
    weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max
-1.7679 -0.6090  0.1507  0.6884  1.3650

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)    -0.214390   0.753580  -0.284  0.77968
n_uptake_kg_ha  0.028653   0.008157   3.513  0.00289 **

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.9477 on 16 degrees of freedom
  (182 observations deleted due to missingness)
Multiple R-squared:  0.4354, Adjusted R-squared:  0.4001
F-statistic: 12.34 on 1 and 16 DF,  p-value: 0.002886
```



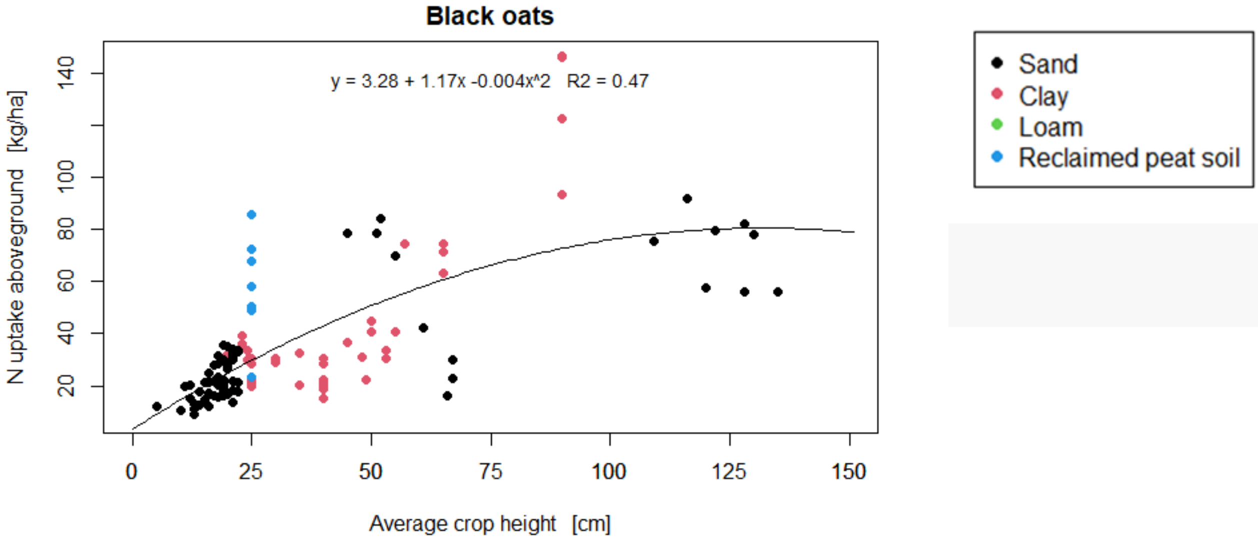
7.10 N uptake vs. crop height

7.10.1 Winter rye



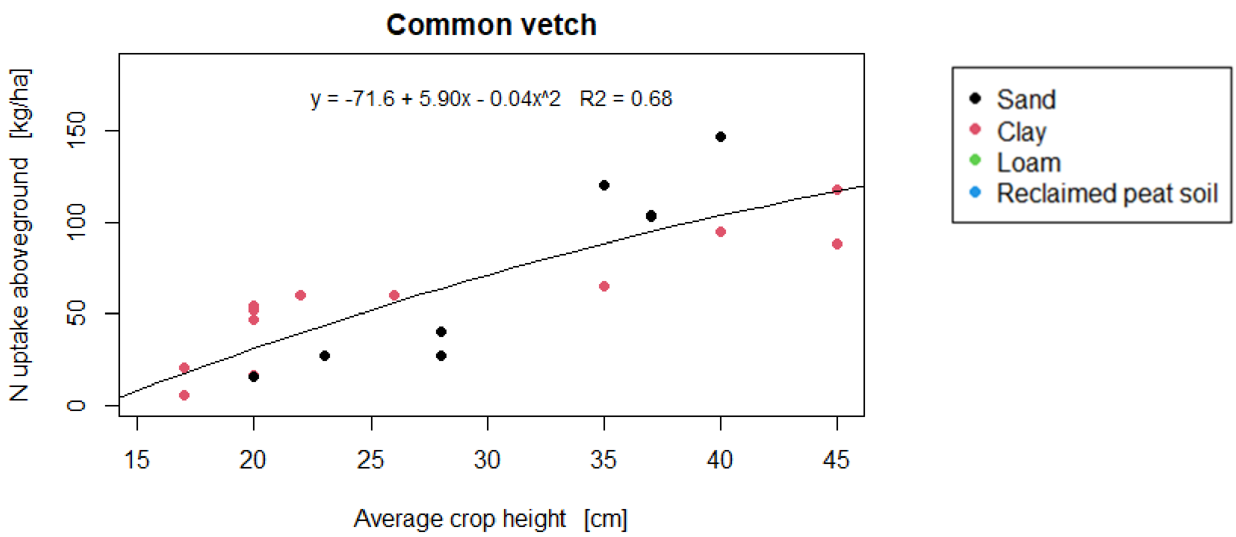
7.10.2 Black oats

```
lm(formula = (n_uptake_kg_ha) ~ average_crop_height_cm + h2,
    data = b_oats_data, weights = weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max 
-45.089  -9.007  -2.650   6.464  73.848 

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)    
(Intercept)             3.279971   5.440673   0.603   0.5479    
average_crop_height_cm  1.171657   0.238212   4.919 3.11e-06 ***
h2                     -0.004442   0.001792  -2.480   0.0147 *  

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 19.7 on 109 degrees of freedom
  (268 observations deleted due to missingness)
Multiple R-squared:  0.4811, Adjusted R-squared:  0.4716 
F-statistic: 50.53 on 2 and 109 DF,  p-value: 2.964e-16
```



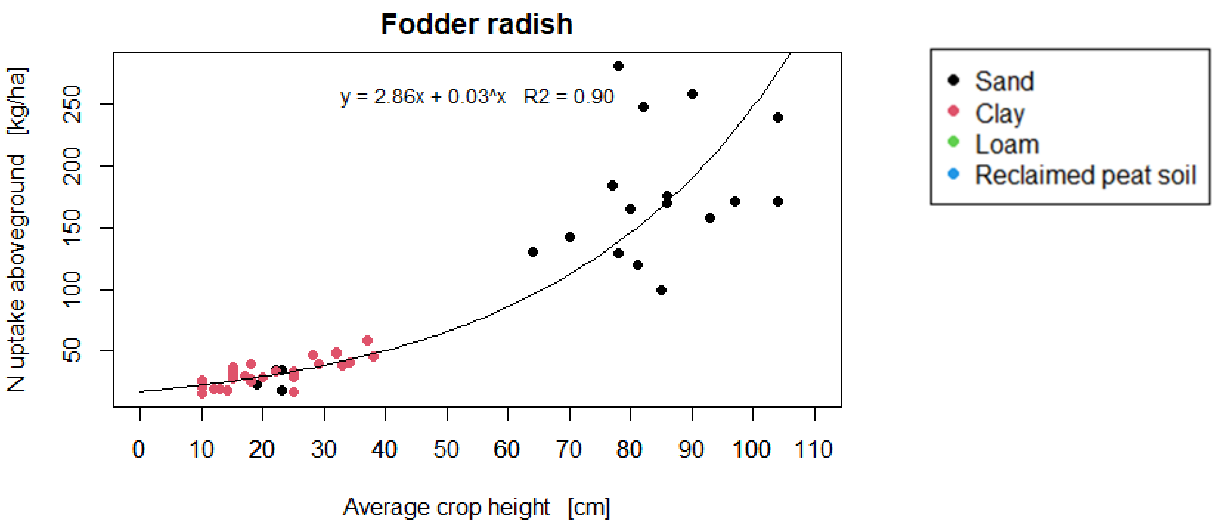
7.10.3 Common vetch

```
lm(formula = n_uptake_kg_ha ~ average_crop_height_cm + h2, data = c_vetch_data,
    weights = c_vetch_data$weight_repetitions_above)

Residuals:
    Min      1Q  Median      3Q     Max 
-36.200 -15.979   2.088  16.563  43.299 

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            -71.57675   68.47564  -1.045    0.311
average_crop_height_cm   5.90430    4.86432   1.214    0.241
h2                      -0.03819    0.07936  -0.481    0.637

Residual standard error: 22.81 on 17 degrees of freedom
  (198 observations deleted due to missingness)
Multiple R-squared:  0.7171, Adjusted R-squared:  0.6838 
F-statistic: 21.55 on 2 and 17 DF,  p-value: 2.18e-05
```

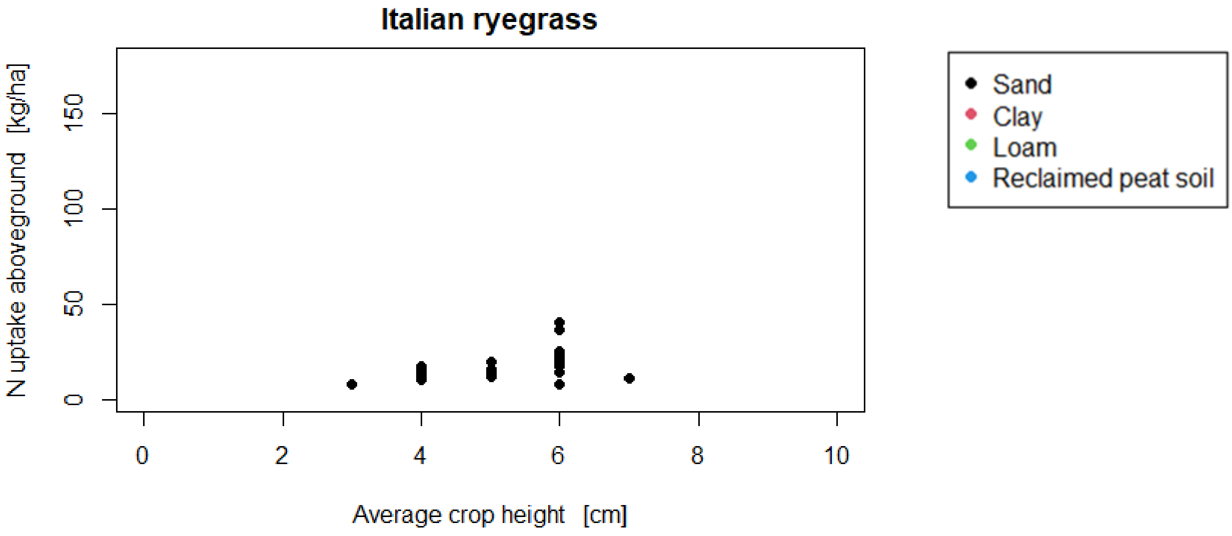


7.10.4 Fodder radish

```
Call:
lm(formula = log(n_uptake_kg_ha) ~ average_crop_height_cm, data = f_radish_data,
    weights = weight_repetitions_above)

Residuals:
     Min       1Q   Median       3Q      Max
-0.69688 -0.14897 -0.00668  0.18951  0.70762

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            2.864239   0.062924   45.52   <2e-16 ***
average_crop_height_cm 0.026489   0.001236   21.44   <2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.273 on 50 degrees of freedom
  (244 observations deleted due to missingness)
Multiple R-squared:  0.9019, Adjusted R-squared:  0.8999
F-statistic: 459.6 on 1 and 50 DF,  p-value: < 2.2e-16
```

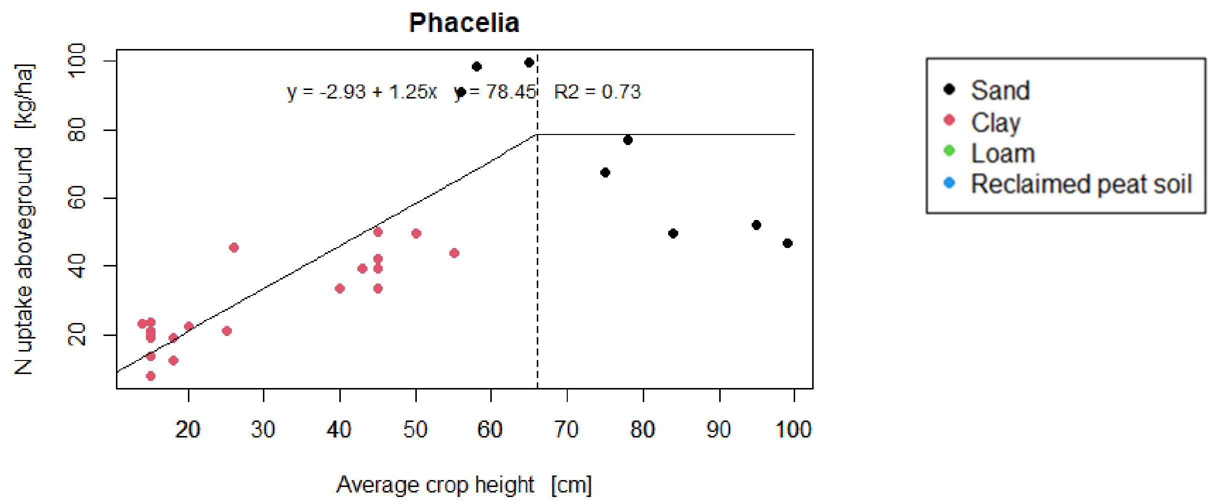


7.10.5 Italian ryegrass

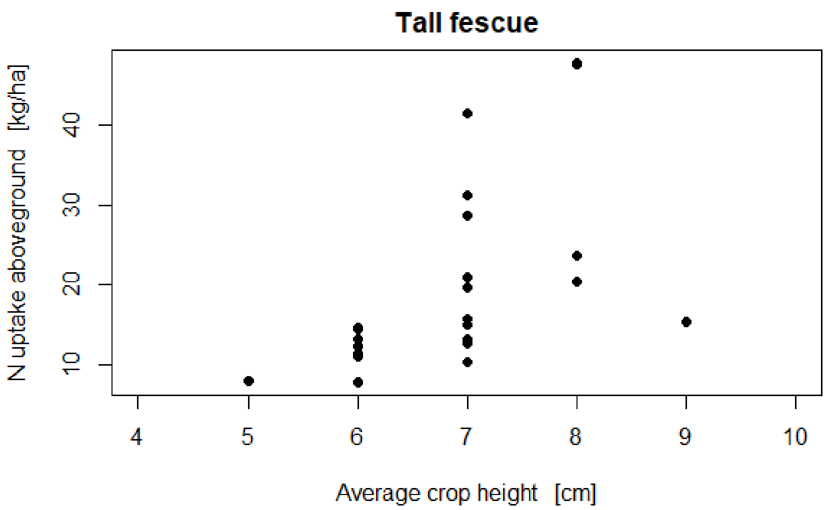


7.10.6 Phacelia

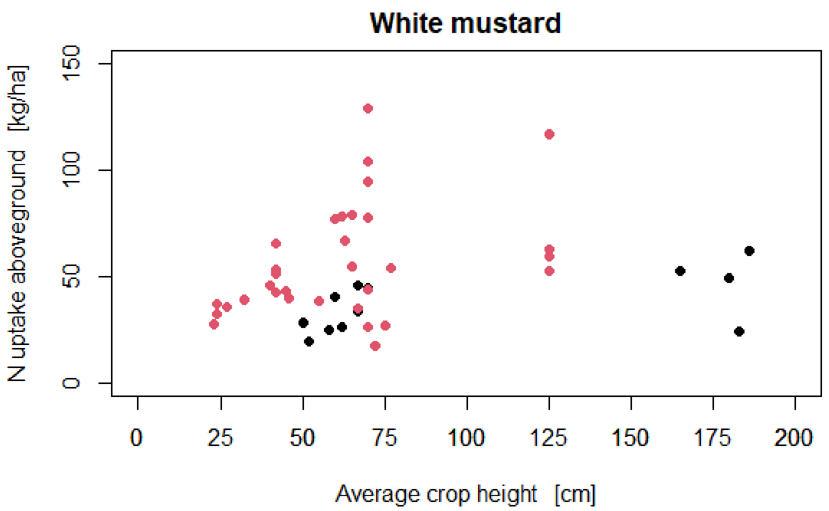
```
 ***Regression Model with Segmented Relationship(s)***
segmented.lm(obj = h_phac_lm1)

Estimated Break-Point(s):
                             Est. St.Err
psi1.average_crop_height_cm 65.585  6.791

Meaningful coefficients of the linear terms:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                -2.9308     5.4774  -0.535    0.597
average_crop_height_cm      1.2519     0.1528   8.196 1.12e-08 ***
U1.average_crop_height_cm  -2.2483     0.6418  -3.503       NA
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 13.06 on 26 degrees of freedom
Multiple R-Squared: 0.7585,  Adjusted R-squared: 0.7307

Convergence attained in 2 iter. (rel. change 5.9962e-07)
$average_crop_height_cm
          Est. St.Err. t value CI(95%).l CI(95%).u
slope1  1.2519 0.15276  8.1957   0.93795   1.56590
slope2 -0.9964 0.62332 -1.5985  -2.27760   0.28485

Davies' test for a change in the slope
data:  formula = n_uptake_kg_ha ~ average_crop_height_cm ,   method = lm
model = gaussian , link = identity
segmented variable = average_crop_height_cm
'best' at = 68.333, n.points = 10, p-value = 0.00028
alternative hypothesis: two.sided
```



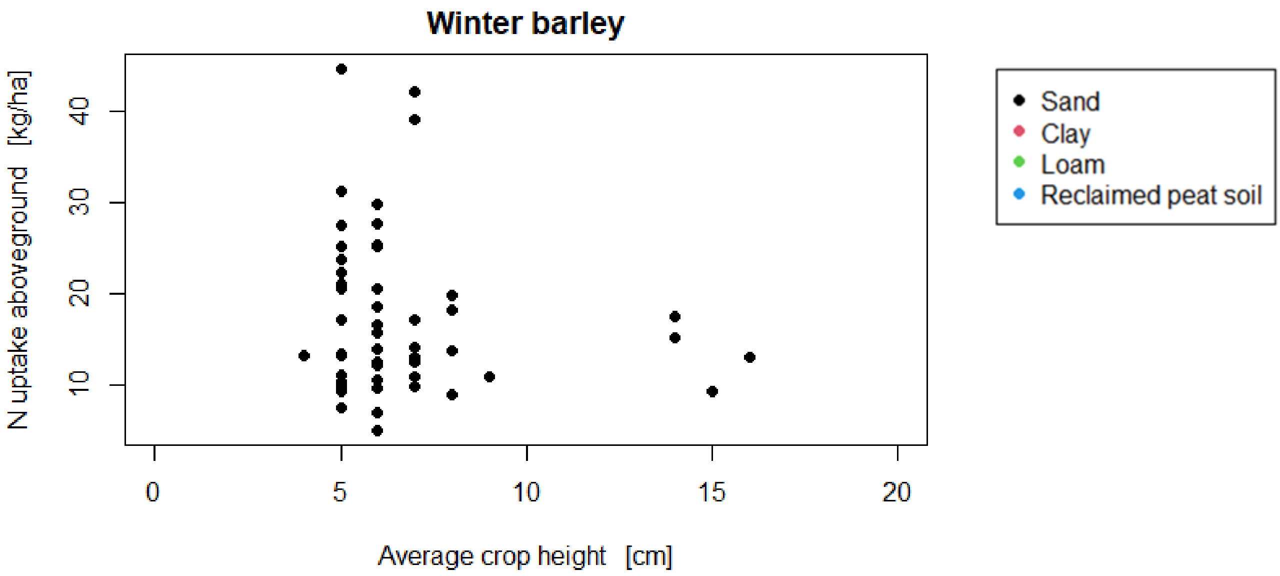
7.10.7 Tall fescue



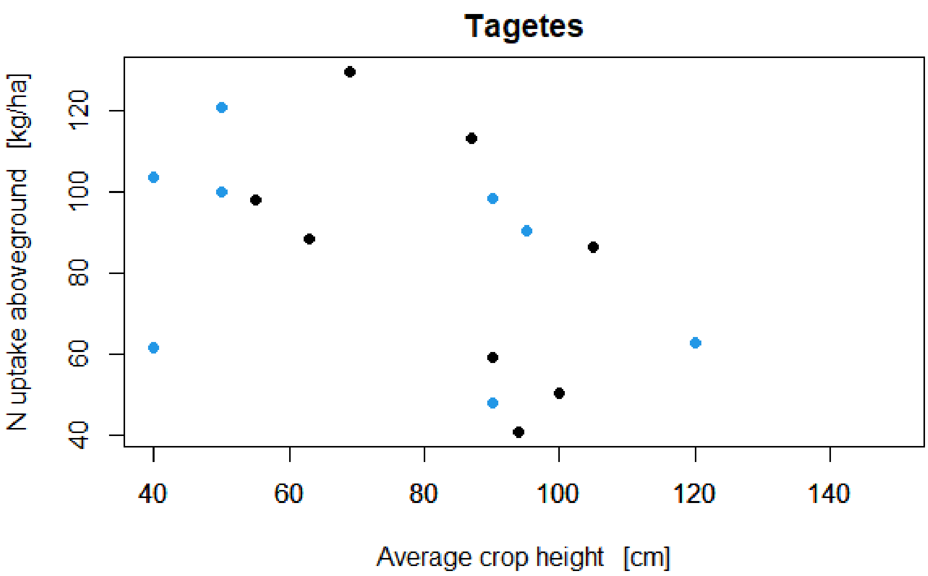
7.10.8 White mustard



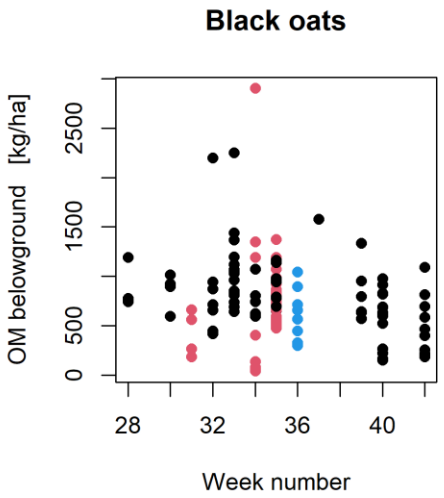
7.10.9 Winter barley

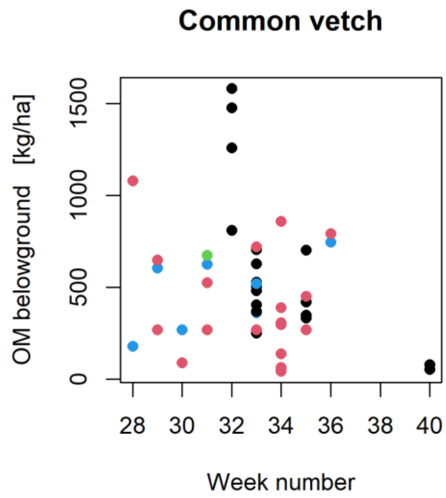


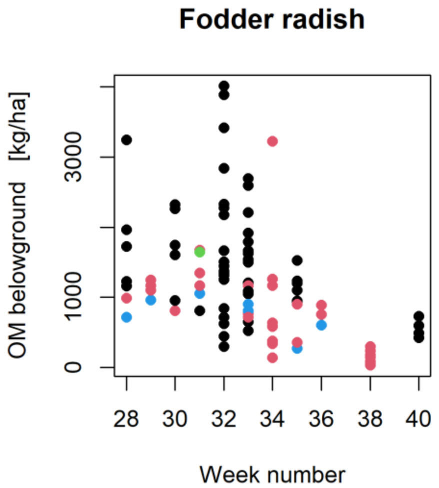
7.10.10 Tagetes

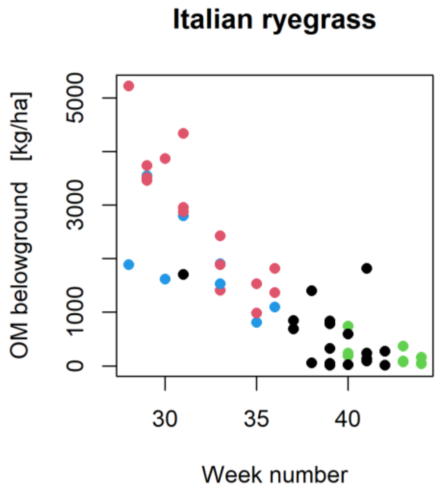


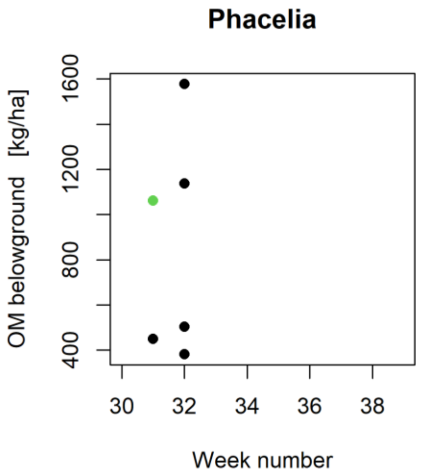
7.11 Belowground biomass

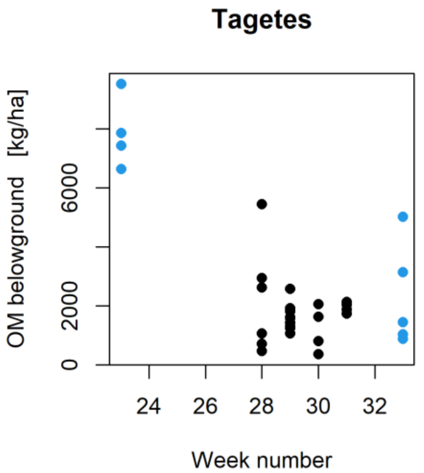


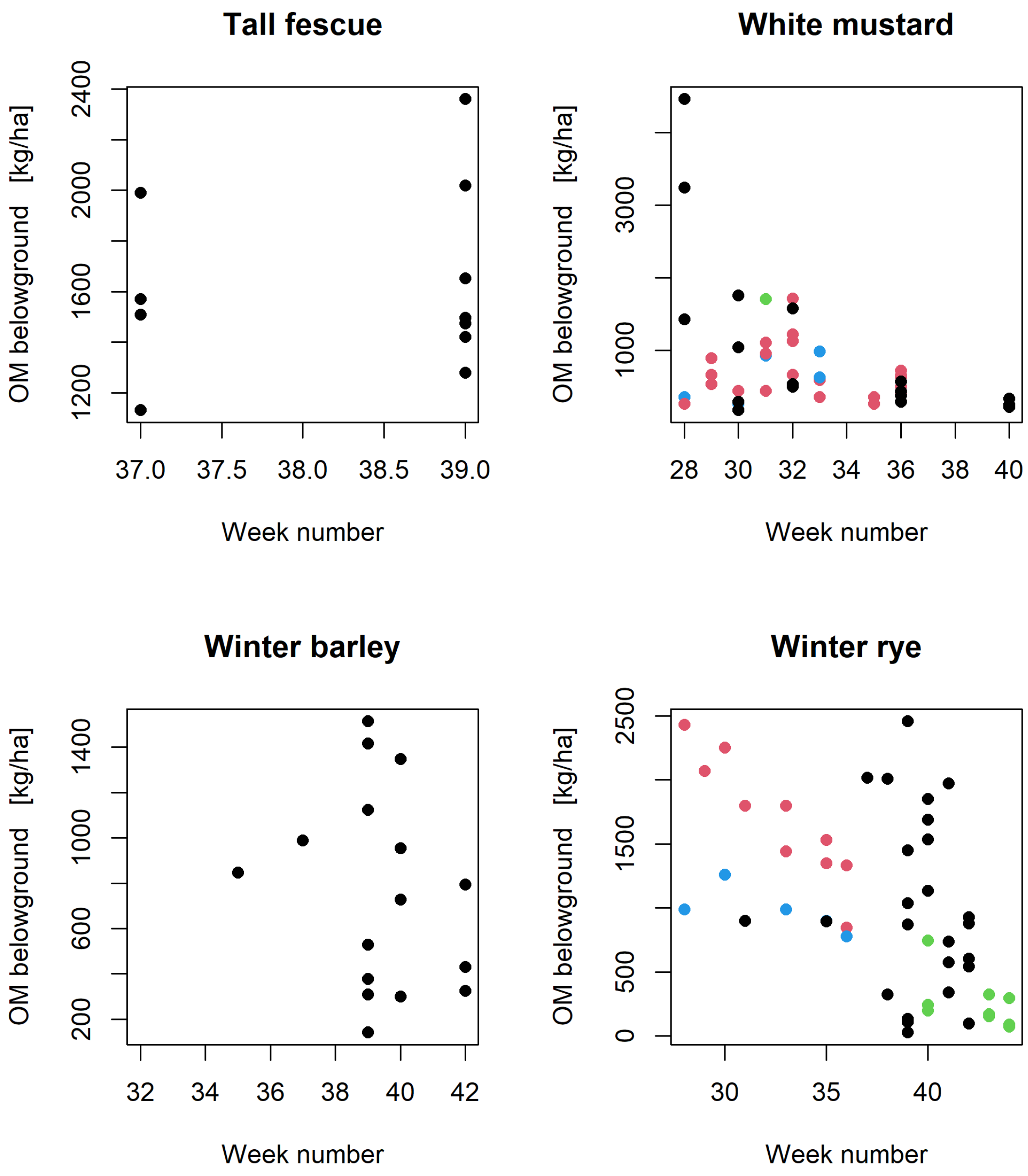











Tall fescue
OM belowground [kg/ha]
1200
1600
2000
2400
37.0
37.5
38.0
38.5
39.0
Week number
White mustard
OM belowground [kg/ha]
1000
3000
28
30
32
34
36
38
40
Week number
Winter barley
OM belowground [kg/ha]
200
600
1000
1400
32
34
36
38
40
42
Week number
Winter rye
OM belowground [kg/ha]
0
500
1500
2500
30
35
40
Week number