Slim Landgebruik

Reference values for arable crop residues: organic matter and C:N ratio

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Summary: Reference values for effective organic matter (EOM) values are used for calculating the organic matter input to soils. In order to update the EOM reference values of crop residues, biomass data was gathered from twelve common arable crops and an incubation experiment was conducted to determine humification coefficients, which is used to calculate the EOM input. The results of this study do not lead to a change in the current humification coefficients. This report proposes new reference values for (effective)organic matter and C:N ratio of crop residues.

Keywords: reference value, crop residue, effective organic matter, organic matter, humification coefficient, C:N ratio, potato, sugar beet, maize, wheat, barley, grass seed

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Slim Landgebruik

WAGENINGEN UNIVERSITY & RESEARCH

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Preface

In this report we aim to update the reference values for the effective organic matter and the C:N ratio of crop residues from twelve arable crops. Reference values for effective organic matter are available in the *Handboek Bodem en Bemesting* (www.handboekbodemenbemesting.nl), which is managed by the *Commissie Bemesting Akkerbouw/Vollegrondsgroenteteelt* (CBAV), with funding from the PPS Beter Bodembeheer. This research was initiated by the *Ministry of Agriculture, Nature and Food Quality (LNV)* programme named *Slim Landgebruik*, which focuses on how soils can be sustainably managed for additional carbon sequestration. It was conducted by Wageningen Research.

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The dataset used for this publication is available via: https://doi.org/10.4121/21717965. This dataset only contains the data sampled by WUR.

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 organic matter input is sufficient to maintain the soil organic matter content of the soil. One approach to do this is the use of reference values for effective organic matter (EOM) from 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 mass, minus the ash content, multiplied by the humification coefficient (HC), which is the fraction OM still present one year after incorporation. Some of the current reference values reported in the Dutch *Handboek Bodem en Bemesting* were determined more than 40 years ago. Here we update the current EOM and C:N ratio reference values for the residues of twelve arable crops.

Materials and methods

Field data of OM of crop residues was gathered from international peer-reviewed literature, previous experiments and sampling in the growing seasons of 2020 and 2021. In order to update the HC's, an incubation experiment was conducted, where carbon mineralization was measured to estimate decomposition rates.

Results and discussion

Humification coefficients

The mean HC for aboveground mass was 0.40, for cereal and maize straw 0.48 and for roots 0.45. Due to the small sample size and large variation in the data, combined with results that were difficult to explain, no reliable distinction for HC's could be made between plant parts or crops. We concluded to not use the derived HC's for calculating the EOM values in this report, but to keep using the currently recommended HC's.

Effective organic matter

No factors were found that could predict crop residue biomass, which would allow for determining more detailed reference values. The main reason was the large variability in the data and hot having a good spread in the data for the different levels of the factors. Based on model-based means and comparison with literature data and current reference values, new reference values were proposed (Table 9). For grain cereals, the new measurements resulted in large differences in total EOM compared to the current reference values. The root biomass and the straw biomass was generally higher than the current reference values. It is difficult to explain a reason for these differences. For potatoes, sugar beet and grass seed, we found considerably lower values than the current reference values, which could partly be explained by changes in crop varieties and management. Silage maize and grain maize had an increase compared to the current reference values which could be explained by the introduction of new improved varieties. For onion, there was no difference between the new values and the current reference values. Since the background information on the currently used reference values is very poor, it is generally difficult to explain the differences between the current reference values and the new measurements.

Table 1. Suggested new reference values of organic matter (OM) and effective organic matter (EOM) of arable crops, in kg per ha and C:N ratio. Values for (E)OM are rounded to the nearest 10 kg per ha per plant part and to the nearest 50 or 100 kg per ha for the total. Note that these are indications and that in practice, the spread around these values is large. For a judgement of the level of substantiation of these values, see the specific crop section in chapter 3.

kg per ha	Organic matter				Effective organic matter				C:N ratio
Crop	Aboveground		Belowground	Total	Aboveground		Belowground	Total	
	Stubble	Straw			Stubble	Straw			
Spring wheat	1330	-	2570	3900	400	-	900	1300	61
Spring wheat straw incorporated	1330	5700	2570	9600	400	1710	900	3000	61
Winter wheat	2560	-	2490	5100	770	-	870	1600	61

Winter wheat, straw incorporated	2560	4230	2490	9300	770	1270	870	2900	61
Spring barley	1770	-	1320	3100	530	-	460	1000	65
Spring barley, straw incorporated	1770	3200	1320	6300	530	960	460	2000	65
Winter barley	2680	-	1780	4500	800	-	620	1400	68
Winter barley, straw incorporated	2680	3840	1780	8300	800	1150	620	2600	68
Sugar beets	3590		420	400	720		150	850	22
Starch potato	3260		440	3700	650		140	800	16
Seed potato	2650		360	3000	530		130	650	20
Ware potato	1400		690	2100	280		180	450	24
Silage maize	950		1470	2400	280		520	800	58
Grain maize	6510		1370	7900	1950		480	2400	47
Seed onion	1350		30	1500	270		10	300	20
Grass seed – English ryegrass 1st year *	1230		2070	3300	250		720	1000	27
Grass seed – English ryegrass 2nd year *	1140		2730	3900	250		950	1200	28

* With incorporation in September, after harvest of seed and hay. Incorporation at a later moment would increase this value due to regrowth of the crop.

Conclusion and recommendations

The compiled dataset and the suggested reference values constitute the most extensive and detailed information on the organic matter from residues of arable crops, grown under Dutch conditions. Therefore, it can provide a valuable contribution to more accurate organic matter management. The differences with the current reference values are for a large part explainable and both increases as well as decreases in the values were observed. Due to the large range in measured values, for some crops we recommend additional and targeted sampling that could contribute to further refinement of these values. For the cereals we specifically recommend to sample ear- and straw harvest since these were not measured in this study and to keep using the current reference values for this plant part. Additionally, we recommend further research on determination of humification coefficients of crop residues since the HC has a large influence on the EOM values. The results from this study have contributed to an update of the reference values of EOM of crop residues In the *Handboek Bodem en Bemesting* (www.handboekbodemenbemesting.nl).

Samenvatting

Inleiding

Goed beheer van de bodemorganische stof (OS) is belangrijk om de bodemkwaliteit in stand te houden. Met een organische-stofbalans kan een agrariër of adviseur een inschatting maken of de organische-stofaanvoer voldoende is om het bodemorganische-stofgehalte op peil te houden. Een methode om de balans op te stellen is door middel van het gebruik van kengetallen voor de effectieve organische stof aanvoer (EOS) van mest, gewasresten en groenbemesters. De EOS is de hoeveelheid van de OS die in de bodem nog aanwezig is één jaar na het inwerken. Het wordt berekend door het droge stof, minus het ruw as-gehalte, te vermenigvuldigen met de humificatiecoëfficiënt (HC). De HC is de fractie van de OS die in de bodem nog aanwezig is één jaar na inwerken. Een deel van de huidige kengetallen in het *Handboek Bodem en Bemesting* zijn meer dan 40 jaar geleden vastgesteld. Daarom worden in dit rapport de huidige kengetallen voor EOS en C:N-ratio van gewasresten van twaalf gewassen geactualiseerd.

Materiaal en methode

Data van veldmetingen werd verzameld uit internationale peer-reviewed literatuur, eerdere experimenten en bemonsteringen in 2020 en 2021. Daarnaast werd een incubatie-experiment uitgevoerd waarbij koolstofmineralisatie gemeten werd om de HC te berekenen.

Resultaten en discussie

Humificatiecoëfficiënten

De gemiddelde HC van de bovengrondse resten was 0,4. In geval van graanstro, maisstoppel en -stengel was de HC gemiddeld 0,48 en voor wortels was die 0,45. Door de kleine hoeveelheid herhalingen en de grote variatie in de data, samen met resultaten die moeilijk te verklaren waren, was het niet mogelijk om nieuwe HC's vast te stellen op het niveau van plantdelen of gewassoort. Er is besloten om de afgeleide HC's niet te gebruiken om de EOS getallen te berekenen in dit rapport, in plaats daarvan zijn de huidige HC's gebruikt.

Effectieve organische stof

Voor geen van de gewassen waren er factoren, zoals grondsoort of opbrengst, die gebruikt konden worden om de hoeveelheid (E)OS te voorspellen om de kengetallen te verfijnen. De belangrijkste reden hiervoor was de grote variabiliteit in de data, samen met weinig data per factorniveau en soms een ongelijkmatige spreiding over verschillende factorniveaus. Op basis van modelmatig opgestelde gemiddelden en vergelijkingen met de literatuurgegevens en huidige kengetallen, zijn nieuwe kengetallen voorgesteld (Tabel 2). Voor granen toonde de nieuwe data aanzienlijke verschillen ten opzichte van de huidige kengetallen, zowel toenames als afnames. Het is moeilijk om deze verschillen te verklaren. Een toename in de EOS werd gevonden voor zowel de wortels als het stro. Voor aardappelen, suikerbiet en graszaad waren de nieuwe getallen aanzienlijk lager dan de huidige kengetallen, wat deels verklaard kan worden door nieuwe rassen en veranderd gewasbeheer. Snijmais en korrelmais toonde een toename in de EOS van gewasresten, vergeleken met de huidige kengetallen, wat mogelijk verklaard kan worden door verbeterde rassen. Voor uien was er geen verschil tussen de nieuwe metingen en het huidige kengetal. Omdat de achterliggende informatie over de huidige kengetallen erg beperkt is, is het niet mogelijk om alle verschillen te verklaren.

Tabel 2. Voorgestelde kengetallen voor organische stof (OS) en effectieve organische stof (EOS) van gewasresten van akkerbouwgewassen, in kg per ha en C:N-ratio. De (E)OS-waardes zijn afgerond tot 10 kg per ha per gewasonderdeel en tot 50 of 100 kg per ha voor het totaal. NB: Deze getallen zijn indicaties, in de praktijk is er een grote spreiding rond deze getallen. Voor een oordeel over de mate van onderbouwing van deze getallen per gewas, zie de specifieke paragraaf in hoofdstuk 3.

kg per ha	Organische stof				Effectieve organische stof				C:N ratio
Gewas	Bovengronds		Ondergronds	Totaal	Bovengronds		Ondergronds	Totaal	
	Stoppel	Stro			Stoppel	Stro			
Zomertarwe	1330	-	2570	3900	400	-	900	1300	61

Zomertarwe, stro ingewerkt	1330	5700	2570	9600	400	1710	900	3000	61
Wintertarwe	2560	-	2490	5100	770	-	870	1600	61
Wintertarwe, stro ingewerkt	2560	4230	2490	9300	770	1270	870	2900	61
Zomergerst	1770	-	1320	3100	530	-	460	1000	65
Zomergerst, stro ingewerkt	1770	3200	1320	6300	530	960	460	2000	65
Wintergerst	2680	-	1780	4500	800	-	620	1400	68
Wintergerst, stro ingewerkt	2680	3840	1780	8300	800	1150	620	2600	68
Suikerbiet	3590		420	400	720		150	850	22
Zetmeelaardappel	3260		440	3700	650		140	800	16
Pootaardappel	2650		360	3000	530		130	650	20
Consumptieaardappel	1400		690	2100	280		180	450	24
Snijmais	950		1470	2400	280		520	800	58
Korrelmais	6510		1370	7900	1950		480	2400	47
Zaaiui	1350		30	1500	270		10	300	20
Graszaad – Engels raaigras - 1e jaar*	1230		2070	3300	250		720	1000	27
Graszaad – Engels raaigras 2e jaar *	1140		2730	3900	250		950	1200	28

* Ondergewerkt in September, na oogst van zaad en hooi. Inwerken bij een later tijdstip, zou een hogere waarde geven door de hergroei van het gewas.

Conclusies en aanbevelingen

De opgestelde dataset en de vastgestelde waardes vormen de meest uitgebreide en gedetailleerde informatie van organische stof en C:N-ratio van resten van akkerbouwgewassen onder Nederlandse condities. Hierdoor kan het een belangrijke bijdrage leveren aan een meer nauwkeurig organische-stofbeheer. De verschillen ten opzichte van de huidige kengetallen waren grotendeels te verklaren en er waren zowel toenames als afnames in de getallen. Voor een deel van de gewassen wordt een aanvullende dataverzameling geadviseerd, die kan bijdragen aan verdere verfijning van deze kengetallen. Omdat er voor de granen geen bemonsteringen waren van de aar- en storesten, wordt aanbevolen om de oude kengetallen te blijven gebruiken voor deze gewasonderdelen totdat er aanvullende data beschikbaar zijn. Daarnaast adviseren we verder onderzoek naar humificatiecoëfficiënten omdat deze een grote invloed hebben op de EOS. Deze studie heeft bijgedragen aan het opstellen van geactualiseerde kengetallen voor EOS van gewasresten in het Handboek Bodem en Bemesting (www.handboekbodemenbemesting.nl).

1 Introduction

1.1 The role of organic matter

Management of the organic matter input to the soil is key for maintaining soil quality and a durable crop production. Soil organic matter (SOM) contributes to soil fertility and crop growth in numerous ways such as by binding and buffering of plant nutrients (Murphy, 2015), providing habitat and food for soil organisms (Sapkota et al., 2012; Aldebron et al., 2020), improving soil moisture retention (Lipiec et al., 2006) and improving soil structure (Masri & Ryan, 2006). Besides these functions, the soil organic matter constitutes a form of carbon sequestration and the maintaining and increase thereof is therefore important for mitigating greenhouse gas emissions (Lal, 2004). The soil organic matter can be kept stable or be increased by different sources of organic matter addition to the soil. Organic matter is added to the soil by the application of organic manures and the incorporation of crop residues and cover crops. After incorporation of organic matter, followed by decomposition, nutrients become available in the soil profile from which the growth of succeeding crop can benefit (Rinnofner et al., 2008). In arable systems, the soil organic matter often decreases when too little organic matter is added, due to the process of mineralization as part of decomposition. In order to maintain a balance between the input and decomposition of organic matter, it is valuable to determine the amount of organic matter that is incorporated and decomposed per year for a specific cropping plan.

1.2 Effective organic matter

An organic matter (OM) balance is calculated to get an overview of the inputs and outputs of organic matter in the soil. The effective organic matter (EOM) refers to the amount of OM from an organic matter source that is still present in the soil one year after it was incorporated. The fraction of OM that rapidly decomposes is therefore not included in the EOM. For calculating the OM balance over a given period the EOM is used, as it indicates the potential for build-up of the SOM in the long 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 of crops have been available for many main crops as well as cover crops since the eighties, based on data gathered in the decades before. The currently used EOM reference values are listed in Table 3 (p. 12). The EOM is calculated by subtracting the ash content from the dry weight 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 HC is currently estimated to be 0.2 for fresh and green aboveground biomass, 0.35 for root biomass and 0.30 for ripe cereal straw and maize. It is used as an input parameter in the AMC-model (Clivot et al., 2019) and in Roth-C (Dechow et al., 2019), among others.

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 refer back to the same source. The current humification coefficients 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 of organic amendments are incubation experiments where the CO_2 respiration is measured at different time intervals (Cotrufo et al., 2015; Groenigen & Zwart, 2007; Jäger et al., 2013; Lashermes et al., 2009; Mewes, 2017; Mondini et al., 2017). This method has been applied in several studies on decomposition of organic manures, in which also humification coefficients were determined (Van den Burgt et al., 2011; CDM, 2017; Groenigen & Zwart, 2007; Postma & Ros, 2016; Reinhold et al., 2016; Rietra et al., in press; VLACO, 2015).

Table 3. Current reference values for EOM in kg per ha and the C:N ratio of the twelve most common arable crops in the Netherlands (PAGV,1989; Handboek bodem en bemesting, 2018).

Crop name	Aboveground (stubble)	Belowground	Harvest residues (from ear + straw)	Total	C:N ratio
Spring wheat	630	490	510	1630	75
Spring wheat, straw incorporated	630	490	510 + 960	2590	75
Winter wheat	630	560	450	1640	75
Winter wheat, straw incorporated	630	560	450 + 990	2630	75
Spring barley	570	350	390	1310	75
Spring barley, straw incorporated	570	350	390 + 630	1940	75
Winter barley	630	490	450	1570	75
Winter barley, straw incorporated	630	490	450 + 780	2350	75
Crop name	**Aboveground**	**Belowground**	**Harvest residues**	**Total**	
Sugar beets	140	175	960	1275	23
Starch potatoes	580	175	60	815	-
Seed potatoes	700	175	80	955	20
Ware potatoes	540	175	160	875	36
Silage maize	150	525	-	675	50
Grain maize	1650	525	-	2175	50
Onion	195	105	-	300	30
English ryegrass (seed production) 1st year	470	1280	-	1750	45
English ryegrass (seed production) 2nd year	470	1680	-	2150	-

1.3 Research objective and questions

The reference values for EOM input by crop residues need to be updated since current values originate from measurements made before the 1980's, of which the raw data or information on the methodology is not readily available (PAGV, 1989). Since then, many new crop varieties have been introduced, crop management and harvest practices have changed and breeding may have changed biomass production and allocation of crops. In this study, we gathered biomass data of crop residues to establish new reference values for the EOM and C:N ratio of crop residues of the twelve largest arable crops in the Netherlands (see Table 3). The new values were thereafter compared with the current reference values. Furthermore, we conducted an incubation experiment where we determined the humification coefficient of above- and belowground biomass of seven of these crop species. This report is elaborating further on the reports about EOM reference values by Harms et al. (2018) and Selin-Norén et al. (2021).

2 Materials and methods

2.1 Carbon respiration experiment

The crops that were included in the incubation experiment were sugar beet, potato, maize, onion, grass seed and winter wheat. The shoots and roots were incubated separately, in two repetitions each. For potato, also the baby potatoes were incubated separately. For grain maize, material from the whole aboveground plant (except for the cob), were incubated and for silage maize only the stubble was incubated.

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. 2-4 grams of crop residue was incubated in 150 g of soil in a glass vial, based on the same amount of C (0.71 g). The amount of cover crop residue added to the vial corresponded to an amount that is multiple times higher than that under field conditions (0-30 cm), which is common for these experiments. For all mixtures of crop residue and soil the C:N ratio was approximately 5. Two vials only containing soil were incubated to determine the background CO_2 flux. At all times, the soil moisture was kept at 60% of the water holding capacity of the soil and the temperature at 20 °C. The respiration of carbon dioxide was measured at day 1, 7, 14, 28, 58, 84, 112 and 140. Measurement was done after keeping the vial closed for a short amount of time.

For the analysis, the respiration was averaged for the two repetitions. Subsequently, the integral of the respiration was calculated and followed by a calculation of the amount of decomposed C for each period between the measurements. 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 $R = e^{-k1}$ and $S = e^{-k2}$. The humification coefficients were 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 of crop residues

2.2.1 Database description

Data was gathered from two years of field measurements, already-compiled data from previous experiments where crop residues were sampled, and by literature study of international peer-reviewed and grey literature. Additional information was gathered about the crops from which the residues were sampled regarding the growing conditions, such as variety, country, location, soil type, crop product yield, sowing date and sampling date. Aspects such as seeding density and amount of fertilization were not gathered as the recommendations on these aspects are standardized in order to reach target yields. In total, 454 entries were gathered. Out of these, 27 entries on vegetable crops were not analysed as a part of this report.

2.2.2 Literature data

Data on crop residues was collected from 13 different sources of international peer-reviewed and grey literature from the years 1990-2019 (Harms et al., 2018; Harms, 2019 (not published)). Only studies from countries with similar climatic conditions and crop yields as in the Netherlands were included. In total 37 entries were gathered from the countries Belgium, Denmark, Germany, Sweden and the UK. The protocol used for sampling in these studies is most likely very variable, however it is assumed that use of this data next to our own data is acceptable as biomass determination is a relatively simple procedure. See Table 10 for an overview of the studies from which literature data was gathered. Finally, another 38 entries were gathered from the straw of spring barley using data from previous own experiments.

2.2.3 Field sampling methodology

In the growing seasons of 2020 and 2021 measurements were made in field experiments as well as in farmer fields, on three different soil types: sand, clay and reclaimed peat soil. The growing season of 2020 was very hot, sunny, slightly dry but with a normal amount of precipitation during the summer months. This could have led to less straw production in cereals and a higher harvest index. The growing season of 2021 had average temperatures with the exception of a cool spring and very hot June. The summer was slightly moist. Both growing seasons can be considered to be representative. The objects for sampling were selected to get a representative selection of different varieties of each crop species grown under different conditions. As far as possible, the same varieties were sampled in both years. The number of measured plots per measured object ranged from two to four plots.

The sampling protocol was adjusted per crop, mainly with variation regarding the size of the sampling plot and the moment of sampling. Samples were taken close to the harvest moment of the crop, as earlier sampling would be misrepresentative since some crops reallocate dry matter to the harvested product in the period before the harvest. The aboveground biomass from the plot area was cut at 1-3 cm above the soil. For all cereals and the grass seed crop, within the same plot from which the aboveground biomass was sampled, six soil cores with a diameter of 7.5, 8 or 15 cm (depending on location) were sampled until 30 cm depth, three diagonally within the row (i.e. on top of the crop) and three diagonally between the rows. For the other crops, roots including harvested goods were carefully dug out manually from the whole plot area. The roots were rinsed from soil, however 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 after washing a few samples. Aboveground biomass and cleaned root samples were subsequently dried at 70 ℃ for up to 72 hours, followed by weighing to determine the dry matter biomass. The dried above- and belowground samples were thereafter chemically analysed for ash and nitrogen content using accredited and certified methods (Eurofins, 2020).

Sampling details per crop type or crop species:

- **Cereal crops** had their aboveground biomass harvested from 0.25, 0.50 or 0.75 m^2. The straw and stubble were manually separated at standard harvesting height (10-15 cm) and the ears were removed. Grain yields were also determined from the plots or from the whole field in order to be able to calculate the harvest index. The contribution of ear residues (central column, chaff and spikelets) to the crop residues was not measured. There was also no measurement of the harvest residues of straw, i.e. the straw that the baler does not gather. Only the total of potentially harvested straw was sampled. Cereal sampling was done just before the crop harvest. Cereal variety trials and farmer fields were used for this sampling.
- **Sugar beets** were harvested from an area of 1 m^2. The head, roots, and root tips were all gathered so as to mimic the effect of a machine harvest. The head is included in the aboveground biomass. The sampling was done just before the final harvest in autumn, mainly in October.
- **Potatoes** were manually sampled for aboveground biomass from an area of 0.75 m^2 and roots, stolons and small-sized potatoes (<22-28 mm, depending on crop) were manually extracted from the soil. Small-sized potatoes were weighed and analysed separately from the roots. The sampling was done just before leaf termination, which is when the growth of the plant is halted but dying leaves are still available for sampling. Additionally, data was compiled, per sampled variety, on earliness class ("vroegrijpheid") and leaf development ("loofontwikkeling") class, following the Dutch classification system of the Dutch national catalogue of potato varieties.

- **Maize** was sampled by harvesting ten plants per plot in 2020, and from an area of 0.75 m^2 or 1,5 m^2 in 2021. In 2020 the biomass of 10 plants was calculated to kg per hectare by using the plant density. The sampling was done in maize variety trials across the country shortly before harvest. Maize varieties with a varying height and thickness of stem were selected. Silage maize stubble was cut-off at standard machine harvesting height.
- **Seed onions** were sampled from an area of 0.75 m^2. This was done at the moment when the leaves had started to turn yellow.
- The **English ryegrass for seed production** was harvested at the most common moment for crop termination, in september, shortly after the harvest of the seed and hay. Dead leaves and roots were excluded, as far as that was possible. Only English ryegrass was sampled, since it is by far the most common species for seed production.

2.3 Data analysis

The results from the incubation experiment were analysed by calculating various mean values and 95% confidence intervals in Microsoft Excel, as the dataset was too small for other analyses.

The analysis of crop residue organic matter and C:N ratio was done in RStudio (RStudio Team, 2020). The raw output from the analysis is available in appendix 2 and 3. The analysis focused on variables of each plant part separately (including straw and baby potatoes). The following steps were taken to establish new reference values:

1. **Data calculations, cleaning and exploration**
   a. The organic matter was calculated by subtracting the ash from the dry matter. If ash wasn't chemically analysed, it was assumed to be 10% of the dry matter (data not sampled in 2020 and 2021). The C:N ratio was calculated assuming carbon to be 45% of the organic matter.
   b. Histograms and boxplots of the data of each variable were studied. The outliers identified in the boxplots were indicated and excluded in the original dataset file. This corresponds to removing the data that falls outside the whiskers in the boxplot, which is 1.5 times the interquartile range (IQR) away from the central box. This is motivated by the aim of the study being establishing reference values.
   c. Data was viewed in boxplots separated for the factors year and soil type, in order to investigate the sources of variation. When the number and quality of data entries allowed it, the relation between aboveground residue and product fresh or dry matter yield was screened on relevant visual trends.
2. **Statistical testing for comparison with current reference values and other crop types**
   a. The Shapiro test for normality, the Kolmogorov-Smirnov test and histograms were used, followed by a log- or a square root- transformation, if needed to achieve a normal distribution.
   b. One-sample T-tests or Wilcoxon signed rank tests were performed on the measured data of all plant parts separately to compare the new data and the current reference value. A Kruskal-Wallis test was used in case of multiple comparisons. An α of 0.05 was used for statistical testing.
   c. For potato and grass seed, tests were performed to compare whether the crop types have significantly different biomass, which would motivate the use of different reference values for each type. For the cereals, a test for comparing the new data with the current reference value for "Harvest residues" was not performed as this refers to ear residues and straw residues, which have not been sampled. For the aboveground biomass of sugar beet, the test was done with the current reference values for aboveground biomass and harvest residues combined into one value.
3. **Establishing reference values**
   a. A linear model was fit to each crop part for the OM and C:N ratio, with the most complex model containing the variables year, soil type, cultivar and an interaction of soil type and location. For this analysis the package lme4 (Bates et al., 2015) was used. Only for some of the literature data, weights were used for the modelling based on the number of repetitions of samples the entry in the database was based on. The weights are not included in the histograms of the appendices. The overall estimated marginal mean (EMM) across the factors was extracted for use as reference value,

by using the package emmeans (Russel et al., 2021). For some variables, a mean was used instead of the EMM due to lack of data and/or poor model fit.

i. Cereals: For a part of the cereal entries only the combination of stubble plus straw was measured resulting in that that OM values were not available for stubble and straw separately. This stubble + straw variable was analysed as a separate fourth variable for the cereals. In order to establish reference values for stubble and straw separately, a weighted mean was calculated from the estimated marginal means of the models by using the calculated (summed) value of the separate measurements of stubble and straw, and the value of the measurements with combined plant parts (stubble+straw). The weights were based on the number of data entries for the variable (for the calculated stubble and straw value the minimum number of entries of the two variables was used). Thereafter, reference values for stubble and straw were calculated by using the ratio of the separately measured stubble and straw. For the C:N ratio a weighted mean for the aboveground biomass was calculated using stubble, straw and stubble+straw data.

ii. Seed onions: The onion bulbs left on the field after harvest were not sampled. Expert judgement assumes this amount to be 1 ton fresh weight of onion per ha. This comes down to 135 kg OM per ha and 27 kg EOM per ha, assuming 15% dry weight, 90% OM and an HC of 0.2 (1000*0.15*0.9*0.2=27 kg per ha). This amount was added to the total EOM of onions.

b. It was decided to use the current HC's to calculate the EOM of the crop residues, and to not use the HC's resulting from the incubation experiment (see 3.1 for the reasoning). The total EOM was calculated using a HC of 0.2 for aboveground biomass and baby potatoes and an HC of 0.35 for belowground biomass. For cereal straw and stubble and aboveground biomass of maize an HC of 0.3 was used.

c. The total OM and EOM production per plant part was rounded to the nearest 10 kg per ha. Thereafter, the sum of the plant parts was calculated and rounded to the nearest 50 kg per ha when the total was below 1000 kg per ha, and to the nearest 100 kg per ha when the total was higher than 1000 kg per ha. The EOM values were calculated from OM values that were not yet in the rounded form. The C:N ratio was calculated for the crop residues of the whole plant by using the ratios between the plant parts of the OM values.

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3 Results and discussion

In this chapter we first present and discuss the results of the incubation experiments (3.1). Thereafter the results from the analysis of the EOM (3.2) and C:N (3.3) ratio data is presented and discussed. This includes a short overview of all crops together (3.2.1), followed by results and discussion on all grain cereals (3.2.2), all potato crops (3.2.8) and per crop individually (3.2.3 -3.2.15). In the text, comparisons are made between the current reference values and the results of this study. An overview of the current reference values per plant part can be found in Table 3.

3.1 Humification coefficients

3.1.1 Results

The two repetitions of each crop material had similar CO_2 fluxes, while the variation was large between the different plant parts and crop species (Table 4). The measured HC's were generally higher than the currently used HC's (ca. 0.1-0.2 higher). The derived humification coefficients had a total average of 0.43 (95% CI ± 0.08) with a mean of 0.44 for aboveground biomass and 0.42 for belowground biomass (not in table). The mean for aboveground biomass for non-cereals was 0.4 while for cereals it was 0.48. The mean for belowground biomass for roots was 0.45 while for baby potato is was 0.26. Sugar beet roots, consisting largely of the root tip, had an HC of 0.07.

*Table 4. Derived humification coefficients of above- and belowground crop residues. The indicated range of the across-crop averages is the 95% confidence interval. * The value for onion root is derived by linear extrapolation due to poor model fit.*

Plant part	Crop	HC
Aboveground biomass	Sugar beet	0.22
	Potato	0.52
	Seed onion	0.53
	Grass seed	0.35
	Average	**0.40 ± 0.12**
	Winter wheat	0.57
	Maize stubble	0.42
	Maize whole	0.46
	Average	**0.48 ± 0.06**
Belowground biomass	Sugar beet	0.07
	Potato	0.60
	Maize	0.46
	Seed onion*	0.40
	Grass seed	0.60
	Winter wheat	0.56
	Average	**0.45 ± 0.15**
	Baby potato	0.26

3.1.1 Discussion

These results provide an indication that the variation in HC's of crop species and plant parts can be substantial, which means that the current HC's that only have a distinction per plant part could be inaccurate. A similarly large variation is also found in other studies where the same methodology is applied (Rietra et al., 2019). As was also found in the incubation experiments of Selin Noren et al. (2021), the difference in HC between aboveground and belowground biomass (0.44 and 0.42, respectively, in the study of Selin Noren et al. (2021)) is smaller than the difference between the current reference values of the two (0.2 and 0.35, respectively). However, known theory and literature sources conclude that belowground biomass have slower decomposition than aboveground biomass, and is hence expected to have a higher HC (Shahbaz, 2016; Katterer et al., 2011).

That the mean of the measured HC's were higher than the current HC's might have to do with that the current values are based on field experiments and not incubation experiments, as in this study. This might indicate that a conversion is needed from the lab environment to the field environment. The values of this experiment are also generally higher than those found by Selin-Noren et al. (2021), which can possibly be explained by that these crop residues come from more mature plant material than most green manure crops, and is therefore likely to have a higher lignin content and hence a slower decomposition (Stewart et al., 2015). Another possible explanation for high HC's, is the amount of organic matter input that is incubated, as this can have a large effect on the decomposition speed, due to influences from physical protection and priming effects (Shahbaz et al., 2016). However, there are also studies showing that amount does not have an influence on the HC, using this method (Rietra et al., in press). In this experiment, the amount of C added was around 40% higher than in the experiments of Selin Noren et al. (2021). The precise relationship between the amount of organic matter added and the decomposition speed is currently not clear, to the best of our knowing.

Despite the large differences between the measured HC's and the current HC's, there are results that correspond with known theory as well as current reference values. For example, the aboveground biomass for non-cereals had a lower HC than belowground biomass, which is in line with the current humification coefficients. The cereals and maize had a higher mean HC for aboveground biomass than the other crops, but similar to the belowground biomass. This can be explained by the higher lignin content of the residues of these crops, which slows down decomposition (Stewart et al., 2015). For the belowground biomass of the sugar beets and baby potato, low HC's are found, which could be explained by the high amount of easily degradable carbohydrates.

Due to the large and unexplainable variation in the HC values and the low number of repetitions of residues per crop species and plant part, HC values with a distinction for species or plant part cannot be reliably defined based on this experiment. Due to the lack of alternatives, we choose to use the current HC values for determining the EOM reference values in this report. We advise to not change the current HC reference values based on our experiment, instead we recommend more extended research and an adjusted methodology. A short literature review that highlights some additional topics regarding this methodology, its pitfalls and the remaining questions is available in the report of Selin Noren et al. (2021).

3.2 Effective organic matter

Tables with descriptive information on the used data, including the number of objects, number of sampled plots, soil types, literature sources and number of datapoints are available in appendix 1. The output from the data analysis, including descriptive diagrams are available in appendix 2.

3.2.1 Summary for all crops

Figure 1 shows the total OM of the aboveground biomass, including the straw for the cereals. Cereals and grain maize have the highest OM biomass and also the largest variation, next to the sugar beet. In Figure 2 the total OM of the belowground biomass is shown. Grass seed, cereals and maize have the highest belowground OM biomass, as well as the largest variation in the values.

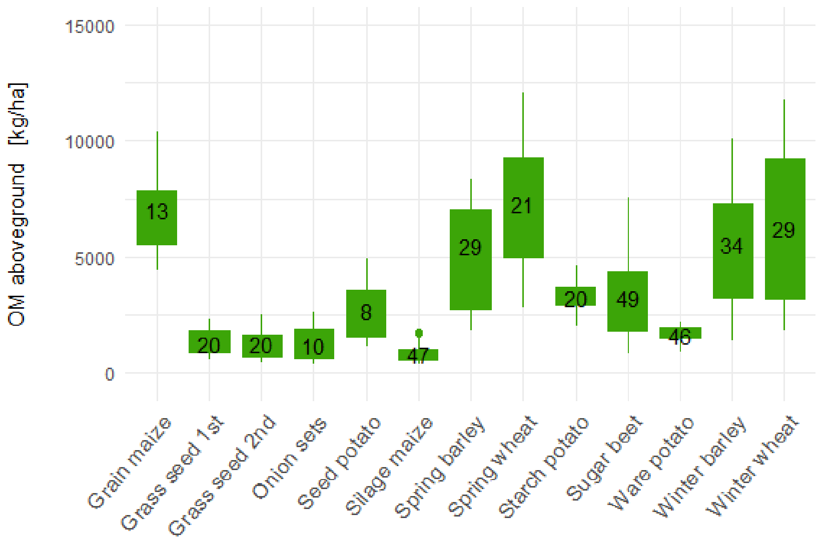

Figure 1. Boxplots of the aboveground OM biomass for all crops. The number in the box indicates the number of data entries. Entries of cereals where only straw or only stubble was measured were not included in this figure.

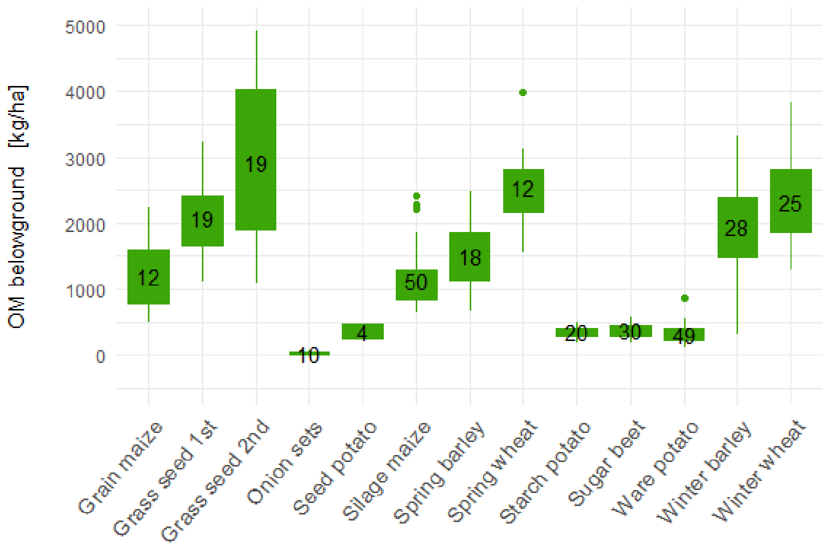

Figure 2. Boxplots of the belowground OM biomass for all crops. The number in the box indicates the number of data entries. When baby potato biomass was missing, only the root biomass was used for this figure.

3.2.2 Cereal crops - general results and discussion

The results for the cereals per plant part are seen in Table 5 and a comparison is made with the current reference values in Table 6.

Table 5. Organic matter and effective organic matter in kg per ha of plant parts of cereal crop residues. Values are rounded to the nearest 10 kg per ha per plant part and to the nearest 100 for the total.

kg per ha	Organic matter				Effective organic matter			
Crop	Aboveground		Below-ground	Total OM	Aboveground		Below-ground	Total EOM
	Stubble	Straw			Stubble	Straw		
Spring wheat	1330	5700	2570	9600	400	1710	900	3000
Winter wheat	2560	4230	2490	9300	770	1270	870	2900
Spring barley	1770	3200	1320	6300	530	960	460	2000

Winter barley	2680	3840	1780	8300	800	1150	620	2600

Table 6. Effective organic matter values of cereals in kg per ha compared with the current EOM reference values. Values are rounded to the nearest 10 kg per ha per plant part and to the nearest 50 or 100 kg per ha for the total.

kg per ha	**Total EOM**		
Crop	**New data**	**Current reference**	**Difference (%)**
Spring wheat	1300	1630	-20
Spring wheat, straw incorporated	3000	2590	+16
Winter wheat	1600	1640	0
Winter wheat, straw incorporated	2900	2630	+11
Spring barley	1000	1310	-24
Spring barley, straw incorporated	2000	1940	+1
Winter barley	1400	1570	-9
Winter barley, straw incorporated	2600	2350	+10

For cereals, a harvest index between 0.4 - 0.6 is considered normal. More extreme values can occur when the crop is affected by drought, for example. Mainly higher, but also lower values than this were measured at multiple occasions in this study, which indicates that some of the data is not representative for an average crop (appendix 2, 2.1). For winter wheat, this resulted in excluding some of the data where a drought effect was plausible. It is however expected that the harvest index has increased somewhat since the current reference values were determined. This might have been achieved by decreased investment in other plant parts than the grains or by more efficient use of resources within the plant to produce grains. Hence, an increase as well as a decrease in total EOM of cereal residues is plausible.

Regarding the comparison between the different cereal crop species and types, there are some unexpected results in the new data:

- For stubble, only a small difference between the species is expected (within ±150 kg EOM per ha). Our data shows a large difference of 400 kg EOM per ha.
- For the roots, a slightly higher mass is expected for the winter crops, however this was only found for barley. The root biomass was generally higher in the new measurements compared to the current reference values. The ratio of roots to the total biomass was nevertheless similar to the current reference values.
- For straw, the wheat and the winter cereals were expected to have a higher biomass, which was also found in our data with an exception for spring wheat having more straw than winter wheat (Table 5).

The mentioned discrepancies between expected and found results do not have a simple explanation or interpretation at hand. A possible source causing discrepancies between the current reference values and the new measured values is with regard to the ear and straw residues. Ear residues have not been sampled in this study and straw residues are now included in the value for straw. Including the ear residues mass would cause an increase in the total values (with *and* without straw), while sampling the straw residues separately would decrease the total mass with straw and increase the total mass without straw.

3.2.3 Spring wheat

Summarizing the results for spring wheat:

- There was a large variation for aboveground biomass in 2020 (a factor of 4-5 between the minimum and maximum value), compared to the variation in 2021. A relationship between yield and aboveground biomass was not apparent, which was also influenced by a lack of data (appendix 2, 3.3, 3.4).

- The value was 400 kg EOM per ha for the stubble which is lower than to the current reference value of 630 kg EOM per ha (Table 5 and Table 6 (appendix 2, 3.1).
- For the belowground biomass the value was 899 kg EOM per ha which is remarkably higher than the current value of 490 kg EOM per ha (appendix 2, 3.2).
- The straw resulted in a value of 1710 kg EOM per ha, which is significantly higher than the current reference value of 960 kg EOM per ha (appendix 2, 3.3, 3.4).
- In total, the EOM with straw is 3009 kg EOM per ha which is higher than the current value of 2590 kg EOM per ha (appendix 2, 3.5). For the total excluding the straw, this value is 1299 kg EOM per ha which is lower than the current reference value of 1630 kg EOM per ha. Tests for comparing with current reference values show that the differences with the current reference values are significant, except for the combined stubble and straw variable (appendix 2, 3.6).

A relatively small amount of data was gathered on spring wheat, which resulted in some of the variables lacking a normal distribution, with large differences in the variation between the two years. Additionally, there was no literature data to compare the findings with. The differences with the current reference values for the total EOM was relatively large while the harvest index was in the normal range.

3.2.4 Winter wheat

Summarizing the results for winter wheat:

- Literature data was available from four sources. There was a large variation for aboveground biomass in 2020 compared to 2021 (for stubble + straw a factor of 6 between the highest and lowest value (appendix 2, 4.1, 4.3, 4.4). For belowground biomass the literature data was slightly lower than the measurements, while for straw the literature data fell in the same range (appendix 2, 4.2, 4.3). A relationship between yield and aboveground biomass was not apparent.
- The value 768 kg EOM per ha for the stubble was higher than current reference value of 630 kg EOM per ha (Table 5 and Table 6**,** appendix 2, 4.1).
- For the belowground biomass the value was 872 kg EOM per ha which is higher than the current value of 560 kg EOM per ha and also higher than the literature value of 520 kg EOM per ha (appendix 2, 4.2).
- The straw had value of 1269 kg EOM per ha, which is higher than the current reference value of 990 kg EOM per ha (appendix 2, 4.3, 4.4).
- In total, the EOM with straw was 2909 kg EOM per ha, which is higher than the current value of 2630 kg EOM per ha (appendix 2, 4.5). For the total excluding straw, this value is 1640 kg EOM per ha which is the same as the current reference value of 1640 kg EOM per ha. Tests for comparing with the current reference values show that the differences are significant for all plant parts (appendix 2, 4.6).

The stubble and the straw and the combined of those had an extremely large range, which together with very high harvest indices suggest that there were some unknown factors influencing the data, such as sampling errors or partly failed, and hence not representative crops. The total EOM of around 1640 kg EOM per ha without straw is similar to the values found by Van Enckevort et al., (2002) who reports an EOM value of about 1605 kg EOM per ha.

3.2.5 Spring barley

Summarizing the results for spring barley:

- Literature data was gathered from two sources. Additionally, 38 entries of straw data were available from internal data from between 2013-2019. There was a large variation for aboveground biomass, but the literature data lied well in the range of the measured data (appendix 2, 5.1, 5.3). There was a factor of 4.8 between the minimum and maximum value. There was no apparent relationship between yield and aboveground biomass.

- The value of 531 kg EOM per ha for the stubble similar to the current reference value of 570 kg EOM per ha (Table 5 and Table 6, appendix 2, 5.1).
- For the belowground biomass, the value of 461 kg EOM per ha was higher than the current value of 350 kg EOM per ha but similar to the literature value of 435 kg EOM per ha (appendix 2, 5.2).
- The straw gave a value of 961 kg EOM per ha, which is higher than the current reference value of 630 kg EOM per ha (appendix 2, 5.3, 5.4).
- In total, the EOM with straw is 1952 kg EOM per ha, which is the same as the current value of 1940 kg EOM per ha (appendix 2, 5.5). For the total excluding straw, this value is 992 kg EOM per ha, which is lower than the current reference value of 1310 kg EOM per ha. Tests for comparing with current reference values show that the new values are significantly different from the current reference values (appendix 2, 5.6).

For several of the variables, the data did not follow the normal distribution. The stubble and the straw and the combination of those had a large range which raises the concern that not all of these values realistically can be found for a successful crop, indicating something else might have affected the crop or the sampling method. However, only a small number of entries had extremes in the harvest index. For straw, the new measurements resulted in higher values compared to multiple years of measurements in another experiment on a sandy soil. However, all of the new measurements are in the range of the literature data (see appendix 2, chapter 5). The total EOM of 1953 kg EOM per ha is similar to the values found by Van Enckevort et al., (2002) who reports an EOM value of about 1940 kg EOM per ha.

3.2.6 Winter barley

Summarizing the results for winter barley:

- The differences were large between the two years (appendix 2, 6.1, 6.3). The factor between the lowest and highest value for aboveground biomass was 7. A relationship between yield and aboveground biomass was not apparent.
- The value was 804 kg EOM per ha for the stubble, which is higher than the current reference value of 630 kg EOM per ha (Table 5 and Table 6).
- For the belowground biomass the value was 624 kg EOM per ha, which is higher than the current value of 490 kg EOM per ha (appendix 2, 6.2).
- The straw gave a value of 1152 kg EOM per ha, which is higher than the current reference value of 780 kg EOM per ha (appendix 2, 6.3, 6.4).
- In total, the EOM with straw is 2579 kg EOM per ha, which higher than current reference value of 2350 kg EOM per ha (appendix 2, 6.5). For the total excluding straw, this value is 1428 kg EOM per ha which is similar to the current reference value of 1570 kg EOM per ha. Tests for comparing with current reference values show that the differences are significant, except for the stubble (appendix 2, 6.6).

The differences in means and the variation were large between the years and many entries showed very high harvest indices, indicating that some unknown factors are influencing the data. The total of 2579 kg EOM per ha is much higher than the value found by Van Enckevort et al., (2002) who reports an EOM value of about 1545 kg EOM per ha.

3.2.7 Sugar beet

The literature data for above- and belowground biomass fell within the range of the measured data (appendix 2, 7.1., 7.2). The variation was large between different years, especially the year 2021 had a large variation. This resulted in a maximum and minimum value with a factor of 9,8 in between. There was no apparent relationship between sugar beet yield and aboveground biomass.

Table 7. Organic matter and effective organic matter values of crops in kg per ha compared with the current EOM reference values. For potatoes, the OM and EOM of the belowground OM are shown as the sum of the roots and baby potatoes. The organic matter of onion harvest residues (bulbs) has been added to the total. Values are rounded to the nearest 10 kg per ha per plant part and to the nearest 50 or 100 for the total.

kg per ha	Organic matter		Effective organic matter			Current reference	Difference	
Crop	Above-ground OM	Below-ground OM	Above-ground EOM	Below-ground EOM	Total EOM	Total EOM	Total EOM	Total EOM (%)
Sugar beets	3590	420	720	150	850	1275	-413	-32%
Starch potato	3260	440	650	140	800	815	-22	-3%
Seed potato	2650	360	530	130	650	955	-298	-31%
Ware potato	1400	690	280	180	450	875	-418	-48%
Silage maize	950	1470	280	520	800	675	124	18%
Grain maize	6510	1370	1950	480	2400	2175	256	12%
Seed onion	1350	30	270	10	300	300	8	3%
Grass seed – English ryegrass 1st year	1230	2070	250	720	1000	1750	-781	-45%
Grass seed – English ryegrass 2nd year	1140	2730	230	950	1200	2150	-968	-45%

The new data give a total of 850 kg EOM per ha which is considerably lower than current reference value of 1275 kg EOM per ha (Table 7). The mean of the literature data was even lower, 620 kg EOM per ha. Differences with current reference values were statistically significant (appendix 2, 7.3).

The analysis showed a ~400 kg EOM per ha lower value than the current reference value, which is a remarkable amount. The lower value was also find in literature. However, our value was much lower than the values found by Van Enckevort et al., (2002) who reports an EOM value of about 1260 kg EOM per ha. Based on the comparison between the analysis results and the current reference values, there are several possible explanations for this decrease. Breeding is likely to have had a negative impact on the amount of leaf residues, however, the amount of leaf is still much dependent on the variety. Most of the objects were harvested in October, when the total leaf amount has already decreased and some possibly even decomposed into soil organic matter. It is advisable to also harvest sugar beet at earlier harvest moments to see if this makes a large difference for the total EOM amount. Another possible explanation for the decrease is that less of the head of the sugar beet is cut off during harvest since around the year 2006. This implies that less of the head and the tip of the sugar beet are now left on the field than previously. A final explanation is that the nitrogen fertilization has a large impact on the leaf production and has been somewhat decreased during the last 40 years.

3.2.8 Potato crops - general results and discussion

The potato types were expected to differ in crop residue biomass. The seed potato is expected to produce more leaf biomass than the ware potato because of an earlier moment of harvesting, this is also found in our data. The matureness of the leaf biomass when incorporated, which differs per crop type, may also influence the humification coefficient. However, in our calculation we use the same HC for all three crops. The difference between starch potato and ware potato in the current reference values does not have a clear explanation, but could be ascribed to less baby potatoes left behind for the starch potato, which might be what is seen in the new data. In our data, the relative values of the different potato crop types are different than in the current reference values. Seed- and starch potato were sampled expecting only small differences with the ware potato, however the differences were larger than expected (up to 370 kg EOM per ha). The aboveground biomass of ware and starch potato was significantly different while seed potato did not differ significantly from the other two (appendix 2, 8.1). For belowground biomass there were no statistical differences between the potato types (appendix 2, 8.2). The biomass of baby potatoes of ware potato was significantly higher than for the starch potato, but the data had a large variation (appendix 2, 8.3).

There was an indication for a relationship with the moment of harvesting, but more data is needed to establish such a relationship. A linear model was fit between leaf development class and aboveground OM as well as earliness class and aboveground OM. These models were significant, but the data had a large spread per class level and had a poor spread across different soil types which makes it have little value as a prediction model unless more data is gathered that confirms this relationship (appendix 2, 8.4). It was clear that starch potatoes had a higher OM production than the ware and seed potato and had a low earliness class, indicating a late harvesting moment.

3.2.9 Starch potato

Data on starch potato was only available from 2020 and was scarce. A relationship between product yield and aboveground biomass was not possible to establish (appendix 2, 9.1). The value of 652 kg EOM per ha for aboveground biomass is higher than the current reference value of 580 kg EOM per ha (Table 7). The 123 kg EOM per ha for the belowground biomass is lower than the current reference value of 175 kg EOM per ha (appendix 2, 9.2). The 19 kg EOM per ha for the baby potato biomass is lower than the current reference value of 60 kg EOM per ha (appendix 2, 9.3). The found values for belowground biomass and baby potatoes are significantly different from the current reference values while for aboveground biomass they are not (appendix 2, 9.3). The new data gave a total of 793 kg EOM per ha which is similar to the current reference value of 815 kg EOM per ha (Table 7). This total is also similar to the values found by Van Enckevort et al., (2002) who reports an EOM value of about 750 kg EOM per ha for starch potatoes. Due to the low amount of data and only a few sampled plots, it is advisable to gather more data on starch potato. Nevertheless, the new value is not much different from the current reference.

3.2.10 Seed potato

Seed potato was only sampled in 2021 and the data was very scarce. The sample size was eight for aboveground biomass and four for belowground biomass. The value of 530 kg EOM per ha for aboveground biomass is lower than the current reference value of 700 kg EOM per ha (Table 7) (appendix 2, 10.1). The 127 kg EOM per ha for the belowground biomass is also lower than the current reference value of 175 kg EOM per ha (appendix 2, 10.2). The new data give a total of 657 kg EOM per ha, which is lower than the current reference value of 955 kg EOM per ha (Table 7). Possible explanations for this decrease could be the specific varieties that were sampled, as well as variety improvements in the direction of less leaf production. However, due to the low amount of data, it is advisable to gather more data on seed potato from more years and locations.

3.2.11 Ware potato

There were four literature sources, two for aboveground biomass and two for belowground biomass. Plotting the aboveground biomass against product yield showed no relationship (appendix 2, 11.1). The 280 kg EOM per ha for aboveground biomass is significantly lower than the current reference value of 540 kg EOM per ha (Table 7). The literature data is somewhat higher with a value of 387 kg EOM per ha. The aboveground biomass is lower on a sandy soil. This is in contrast to the expectation that aboveground biomass is higher on a sandy soil since the crop height is generally higher. Since the value on sand is based on only two objects, it is not enough substantiation for different reference values for different soil types. It is advised to further investigate this possible distinction between the soil types.

The 94 kg EOM per ha for the belowground biomass is lower than the current reference value of 175 kg EOM per ha (appendix 2, 11.2). The 84 kg EOM per ha for the baby potato biomass is lower than the current reference value of 160 kg EOM per ha (appendix 2, 11.3). In total this gives 457 kg EOM per ha which is lower than the current reference value of 875 kg EOM per ha. All differences with the current reference values are statistically significant (appendix 2, 11.4).

A lower EOM than the current reference value was also found for seed potato. This finding is also in line with what was found in literature. A possible reason for the decrease in aboveground biomass is that the old reference value was probably based on the variety Bintje, which had a high leaf production. The biomass of baby potatoes was smaller than in the current reference values, this could be explained by that for the current reference values it was assumed that 100 kg EOM per ha were brought back to the field after sorting. This is not included in the new values because the baby potatoes are usually not evenly distributed over the field and it can therefore better be considered as an external input for specific fields or parts of fields.

3.2.12 Silage maize

Two literature sources were found. The literature and measured data differed, with the mean of literature aboveground data (342 kg EOM per ha, Komainda et al., 2018) being higher than the estimated marginal mean of the measured data (284 kg EOM per ha) and the literature belowground biomass data (622 kg EOM per ha) (Xu et al., 2019) being higher than the sampled data (515 kg EOM per ha) (Table 7, appendix 2, 12.1). The variation of the measured data was large with a factor of 4.9 between the lowest and the highest value for aboveground biomass. This variation was mainly due to large differences between the two years of measurements. No relationship with crop yield could be established. The value of 284 kg EOM per ha for aboveground biomass is higher than the current reference value of 150 kg EOM per ha. The value of 515 kg EOM per ha for the belowground biomass is similar to the current reference value of 525 kg EOM per ha (appendix 2, 12.2). In total this gives 799 kg EOM per ha, which is somewhat higher than the current reference value of 675 kg EOM per ha. Statistical testing show that the differences with the current reference values are significant (appendix 2, 12.3).

Own measurements as well as literature data suggest a minor increase in the EOM values for silage maize residues. Due to the large variation between two the years and the discrepancies between the measurements and literature data, it is nevertheless recommended to make measurements in more growing years. That the total EOM is similar to the current reference values, while the biomass for the plant parts separately is different, is possibly ascribed to the sampling method, in particular the height of separating aboveground and belowground biomass or the mowing height. It is however not possible to confirm this. Additionally, silage maize have been developed into a main crop in North-Western Europe by intensive breeding over the last decades. Since it is produced for its biomass, also an increase in the residues is possible, which could explain our results.

3.2.13 Grain maize

One literature source was found for the aboveground biomass of grain maize. The literature value of 2160 kg EOM per ha is similar to the value of 1953 kg EOM per ha from our study as well as the current reference value (Table 7). No relationship could be established between aboveground biomass and crop yield (appendix 2, 13.1). The mean for belowground biomass was 478 kg EOM per ha, which is lower than the current reference value of 525 kg EOM per ha (appendix 2, 13.2). This results in a reference value for the total of 2431 kg EOM per ha, which is higher than the current reference value of 2175 kg EOM per ha. Statistical tests show a significantly higher aboveground biomass compared to the current reference values, but no significant difference for belowground biomass (appendix 2, 13.3). That the new value is higher than the current reference value is in line with the expectation, as the varieties have become taller during the last decades.

3.2.14 Seed onion

A very limited amount of data was available on biomass of seed onion (appendix 2, 14.1). On sand, the average is around 410 kg EOM per ha, while on reclaimed peat soil the average is around 120 kg EOM per ha (Table 7). The current reference value lies in between these values, at 300 kg EOM per ha. The belowground biomass had a value of 12 kg EOM per ha compared to the current reference value of 105 kg EOM per ha (appendix 2, 14.2). The difference with the current reference value is only significant for belowground biomass (appendix 2, 14.3). Adding 27 kg EOM per ha for the bulb harvest residues makes the total EOM 308 kg EOM per ha, which is similar to the current reference value of 300 kg EOM per ha. It is also similar to the results found by Van Enckevort et al., (2002) who reports an EOM in residues of about 305 kg EOM per ha. The relatively small (in kg EOM per ha) extra precision gained from more measurements does not motivate more extensive sampling.

3.2.15 Grass seed

All samples were from the same area in north of the Netherlands. Half of the objects were from a 1st year grass seed crop and half were from a 2nd year grass seed crop. Statistical testing show that there is no significant difference between the 1st and 2nd year grass seed crop for the aboveground biomass (appendix 2, 15). For the belowground biomass a marginally non-significant higher biomass for the 2nd year crop is found. A linear model between aboveground biomass and product yield is significantly negative for the 1st year crop (appendix 2, 16.1). The relationship between aboveground biomass and product yield for the 2nd year crop is unclear (appendix 2, 17.1).

For the 1st year crop the variation was large, with a maximum and minimum value with a factor of 4.3 in between. The value of 245 kg EOM per ha for aboveground biomass was lower than the current reference value of 470 kg EOM per ha (Table 7) (appendix 2, 16.1, 16.3). The value of 724 kg EOM per ha for the belowground biomass is significantly lower than the current reference value of 1280 kg EOM per ha (appendix 2, 16.2, 16.3). In total this gives 969 kg EOM per ha which is lower than the current reference value of 1750 kg EOM per ha.

Also for the 2nd year crop the variation was large, with a maximum and minimum value with a factor of 5.8 in between. The value of 227 kg EOM per ha for aboveground biomass is significantly lower than the current reference value of 470 kg EOM per ha (Table 7) (appendix 2, 17.1, 17.3). The value of 954 kg EOM per ha for the belowground biomass is significantly lower than the current reference value of 1680 kg EOM per ha (appendix 2, 17.2, 17.3). In total this gives 1184 kg EOM per ha which is lower than the current reference value of 2150 kg EOM per ha.

As was expected, the aboveground biomass was not much different between the 1st and 2nd year crop, while for the belowground biomass, the 2nd year crop had accumulated significantly more root biomass. For both crops, the value is much lower than the current reference value. A possible reason for a decrease is that in the past the grass seed crop was sown earlier in the season, which allowed for a considerably higher biomass production. The crop was often sown in August, with herbicide application and sometimes grazed by sheep during the winter. Considering a grass seed crop can have a large contribution to the total EOM addition, and that this data was gathered from only two growing years, has a large variation, and all comes from one geographical area, it is advisable to supplement the dataset with more measurements. Sampling should then also be done in other regions with grass seed production. Since in some cases the grass seed crop is kept for a longer period to function as a green manure crop, it is advisable to also sample objects just before incorporation in November-December. The expectation is that the biomass would be significantly higher than when sampling in August-September. When the current reference values were established, this was also an occurring practice, which makes it another possible explanation for the discrepancy between the measured values and the current reference values.

3.3 C:N ratio

A table with an overview of the number of observations in available in appendix 1. The output from the data analysis is available in appendix 3. The C:N ratios were lower than the current reference values for all crops with an exception for silage maize. There is no simple explanation at hand for the lower values. In some crops it could possibly be caused by the residues being sampled a time before the harvest while the current values may be based on analysis at harvest. There were a few outliers in the data that may have caused the higher value in maize, there was however no reason to exclude these outliers. There was no current reference value available for starch potato, these data show that the C:N ratio for starch potato is the same to that of ware potato.

Table 8. C:N ratio of crops compared with the current reference values.

Crop	C:N ratio of crop residues	Current reference value	Difference
Spring wheat	61	75	-14
Winter wheat	61	75	-14
Spring barley	65	75	-10
Winter barley	68	75	-7
Sugar beets	22	23	-1
Starch potato	16	-	-20
Seed potato	20	20	0
Ware potato	24	36	-12
Silage maize	58	50	8
Grain maize	47	50	-3
Seed onion	20	30	-10
Grass seed – English ryegrass 1st year	27	45	-18
Grass seed – English ryegrass 2nd year	28	-	-17

4 General discussion

The discussion regarding the incubation experiment and its results are included in chapter 3.1.1 for ease of reading. In the following paragraphs a general discussion is included regarding the measurements of crop residues and establishment of new reference values.

The variation in data that was observed between the two years of sampling and variables lacking a normal distribution indicate that a few more years of sampling is advisable to retrieve a reliable dataset. The ties between the factors soil type and location (including slight differences in sampling methods) makes it difficult to know what the found differences between soil types can be ascribed to. On the same note, a few of the plant part variables show such a high range in values (factor 4 and above) that it is questionable if all of the data originates from successful and representative crops, sampled and calculated according to the same protocol. Another point to consider is that leaves and roots that die off and decompose before the sampling moment are not included in the measurements. This could play a role in cereals, potatoes, sugar beets and certainly in grass seed. In order to sample this aboveground biomass one would have to gather the residues within the same sampling plot as they die off by recurring measurements, which is very labour intensive.

The presented EOM reference values do not make any distinction in crop residue amount within the crop based on soil type, harvesting date, crop yield or any other variable. For soil type, differences in residues are possible and sometimes expected, but the amount of data per soil type does not allow to make this distinction in the reference values. To establish relationships with factors to be able to produce more detailed reference values, more measurements would be needed with a better spread over different circumstances. It is however sometimes questionable whether more detailed reference values are possible at all due to the inherent large variation caused by different locations, yearly weather conditions, varieties and farm-specific management. When it comes to yield, the yield levels are relatively stable per soil type in the Netherlands and it is unlikely that the small differences in yields seen, would have a strong relationship with the amount of crop residues.

After finishing the sampling of cereals, literature results were found for the dry weight of ear residues in winter wheat (Darwinkel, 1997). On average, the study found that this residue made up 23% of the total aboveground matter. This can amount to more than 100 kg EOM per ha in crop residues. Concluding that this is a meaningful amount, it is advisable to investigate the ratio of ear residues mass to the total mass in all four cereal crops. The expectation is that this will result in higher total EOM values. Additionally, since straw mass is remarkably higher in the new measurements, compared to the current reference values, it may be advisable to directly sample the amount of harvest residues from the straw during the harvesting operation.

Despite these criticisms of this study, this dataset represents the only, as well as the most extensive dataset on crop residues for our climate that is available to our knowing. Unfortunately, there is no dataset or sampling protocols available for the current reference vales to compare our results with. This makes the comparison with the current reference values very speculative. The current reference values for belowground biomass might be based on calculation using ratios and not on extensive measurements. It is likely, that next to the differences expected due to various factors that changed over the last 40 years, that also the method and moment of sampling can have a considerable influence on the measured organic matter. Altogether this argues for the use of these results as reference values as there currently are no alternatives with a better substantiation.

5 Conclusions & recommendations

5.1 Conclusions

The main conclusions and findings of this study are summarized as followed:

- Due to the small sample size and large variation in the data, combined with results that were difficult to explain, no reliable distinction could be made for HC's between plant parts or crops based on our experiment. The results indicate that large differences in HC's between plant part and crop species, also under identical conditions is a possibility. We concluded to not use the derived HC values for calculating the EOM values.
- A dataset of crop residue biomass was compiled from the twelve most grown arable crops in the Netherlands and new reference values for the EOM and C:N ratio of crop residues were proposed (Table 9). The degree of substantiation and certainty of these values differs per crop, which is detailed in chapter 3. Differences between the new values and the current reference values per plant part were statistically significant, with a few exceptions.
- Crop yield, harvest moment or soil type do not come forward as good predictors for crop residue mass for any of the crops, partly due to lack of data with a good spread for different levels of these factors. For potatoes, the leaf development class and the earliness class may have some potential for prediction of crop residue biomass, if more data is gathered for more classes and spread over different soil types.

Table 9. Suggested new reference values of organic matter (OM) and effective organic matter (EOM) of arable crops, in kg per ha and C:N ratio. Values for (E)OM are rounded to the nearest 10 kg per ha per plant part and to the nearest 50 or 100 kg per ha for the total. Note that these are indications and that in reality, the spread around these values is large. For a judgement of the level of substantiation of these values, see the specific crop section in chapter 3.

kg per ha	**Organic matter**				**Effective organic matter**				**C:N ratio**
Crop	**Aboveground**		**Belowground**	**Total**	**Aboveground**		**Belowground**	**Total**	
	Stubble	**Straw**			**Stubble**	**Straw**			
Spring wheat	1330	-	2570	3900	400	-	900	1300	61
Spring wheat straw incorporated	1330	5700	2570	9600	400	1710	900	3000	61
Winter wheat	2560	-	2490	5100	770	-	870	1600	61
Winter wheat, straw incorporated	2560	4230	2490	9300	770	1270	870	2900	61
Spring barley	1770	-	1320	3100	530	-	460	1000	65
Spring barley, straw incorporated	1770	3200	1320	6300	530	960	460	2000	65
Winter barley	2680	-	1780	4500	800	-	620	1400	68
Winter barley, straw incorporated	2680	3840	1780	8300	800	1150	620	2600	68
Sugar beets	3590		420	400	720		150	850	22
Starch potato	3260		440	3700	650		140	800	16
Seed potato	2650		360	3000	530		130	650	20
Ware potato	1400		690	2100	280		180	450	24
Silage maize	950		1470	2400	280		520	800	58
Grain maize	6510		1370	7900	1950		480	2400	47
Seed onion	1350		30	1500	270		10	300	20
Grass seed – English ryegrass 1st year *	1230		2070	3300	250		720	1000	27
Grass seed – English ryegrass 2nd year *	1140		2730	3900	250		950	1200	28

* With incorporation in September, after harvest of seed and hay. Incorporation at a later moment would increase this value due to regrowth of the crop.

- For grain cereals, the new measurements resulted in relatively large changes to total EOM, compared to the current reference values. Main differences were increases in root and straw mass.
- For potatoes, sugar beet and grass seed the measurements gave much lower values that the current reference values which could also be partly explained by changed crop varieties and management factors.
- Silage maize and grain maize showed a small increase in the EOM of the crop residues. This could be explained by breeding advances during the period since the current reference values were established.
- For onions there is no difference between the new data and the current reference values.

5.2 Recommendations

The main recommendations from this study are:

- As continuation of the research on HC's, similar experiments with a considerably larger number of repetitions is recommended, or, another approach and methodology altogether. If HC's are determined under non-field conditions, validation experiments are recommended in order to determine a correction factor. For both steps, influences of different soil types and amount of OM input is worth investigating.
- We 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.
- It is recommended to conduct measurements of crop residues during more than two years, in order to get a more representative and reliable dataset. Targeted gathering of more data would possibly also allow for drawing relations between the amount of crop residues and other factors in order to establish more detailed reference values. Specifically:
    - For cereals additional sampling of the ear residues and straw harvest residues is advised. Until this data is available, it is recommended to keep using the current reference values for straw and harvest residues, whereas the new reference values for stubbles and belowground biomass can be used.
    - For potato it is advised to take more samples from aboveground biomass on sandy soils in order to be able to conclude whether there is a difference per soil type.
    - For sugar beet sampling is advised in other harvesting months than October.
    - For grass seed sampling is advised before incorporation before winter, as well as in other regions than used in this study.
- We advise to also update the reference values of other crops than those included in this study. Especially important crops are different types of grasslands and some common vegetable, bulb and forage crops.

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Appendix 1: Descriptive tables

Table 10. An overview of crops, plant parts, county and soil type of the compiled data from own experiments and literature sources.

Reference	Crop	Plant part	Country	Soil type
Bolinder et al., 2015	ware potato, sugar beet	above- and belowground, small- sized potatoes	various	n.a.
Buysse et al., 2013	sugar beet	aboveground	BE	loam
Hu et al., 2018	spring barley, winter wheat	belowground	DK	loamy sand
Jørgensen et al., 2019	winter wheat	straw	DK	clay
Komainda et al., 2018	silage maize	above- and belowground	DE	sand
Sagoo, L., unpublished, personal communication	savoy cabbage, brussels sprouts	aboveground	UK	loam
Mattsson et al., 1991 , cited by Bolinder et al., 2015	potato	belowground	SE	n.a.
Sleutel et al., 2007	potato, sugar beet, winter wheat, grain and silage maize	straw, aboveground	BE	n.a.
Steen and Andrén, 1990, cited by Bolinder et al., 2015	potato	belowground	SE	n.a.
Thomsen and Christensen, 1998	winter wheat, spring barley, sugar beet	straw	DK	sandy loam
Van Noordwijk et al., 1994, cited by Bolinder et al., 2015	sugar beet	belowground	NL	clay
Xu et al., 2019	maize (silage and grain)	belowground	BE/ IT	loam
De Haan et al., 2018 (own data)	sugar beet, pea leek	aboveground	NL	sand

Table 11. The number of datapoints used per crop and plant part in order to calculate the suggested (E)OM reference values (weights are not included).

Crop	Stubble	Belowground biomass	Straw	Stubble + straw
Spring wheat	16	12	15	6
Winter wheat	21	25	24	18
Spring barley	18	18	69	16
Winter barley	16	28	16	18

Crop	Aboveground biomass	Belowground biomass
Sugar beets	49	30
Starch potato	20	roots: 20, baby potatoes: 20
Seed potato	8	roots: 4, baby potatoes: 0
Ware potato	46	roots: 48, baby potatoes: 39
Silage maize	47	50
Grain maize	13	12
Seed onion	10	10
Grass seed – English ryegrass 1st year	20	19
Grass seed – English ryegrass 2nd year	20	19

Table 12. The number of datapoints used per crop and plant part in order to calculate the C:N ratio reference values.

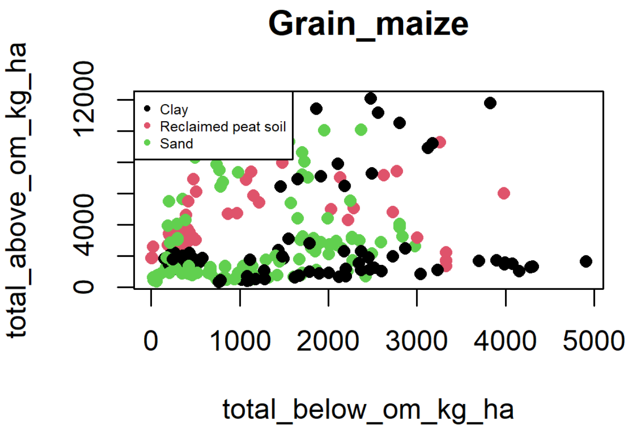
Crop	Stubble	Belowground biomass	Straw	Stubble + straw
Spring wheat	16	10	16	6
Winter wheat	24	24	18	14
Spring barley	18	16	46	16
Winter barley	16	28	16	18
Crop	**Aboveground biomass**	**Belowground biomass**		
Sugar beets	34	30		
Starch potato	20	20		
Seed potato	8	4		
Ware potato	46	(baby potato: 32) 46		
Silage maize	47	47		
Grain maize	12	12		
Seed onion	10	10		
Grass seed – English ryegrass 1st year	20	20		
Grass seed – English ryegrass 2nd year	20	20		

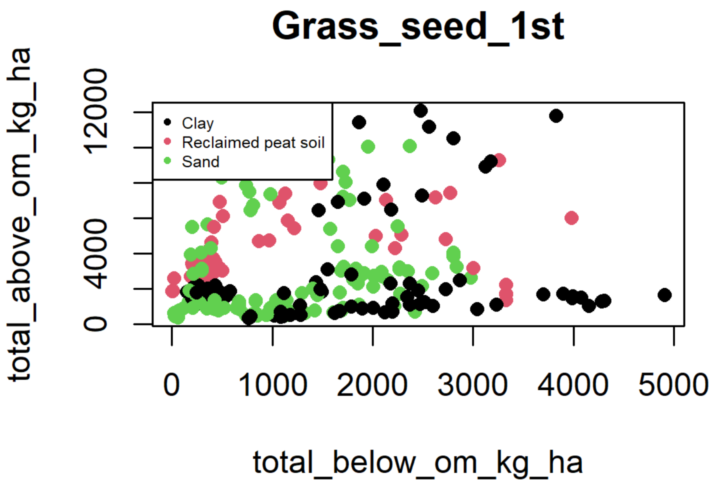
Table 13. Data overview per crop species with the number of objects (combination of location, field, soil type and variety), number of sampled plots, the soil types available per plot and the number of literature sources and data points.

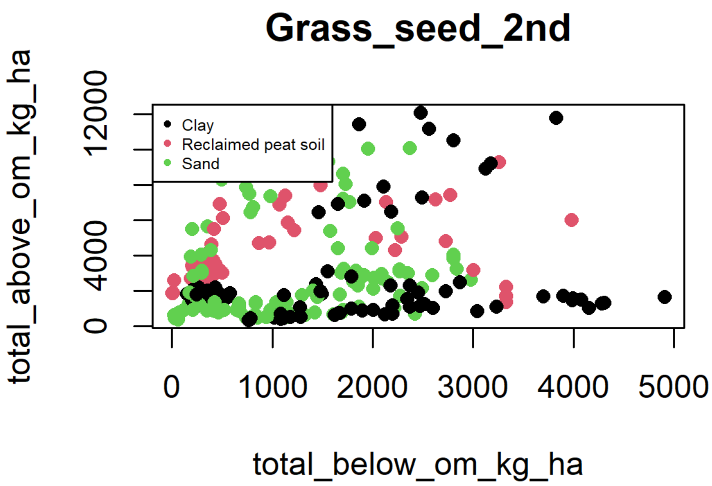
Crop	Nr. of objects	Nr. of sampled plots	Soil types	Literature sources	Other sources
Spring wheat	9	22	reclaimed peat soil, clay	-	-
Winter wheat	13	42	sand, reclaimed peat soil, clay	4 sources, 9 datapoints	-
Spring barley	12	34	sand, reclaimed peat soil, clay	2 sources, 6 datapoints	55 datapoints on straw, each one repetition
Winter barley	10	34	sand, reclaimed peat soil, clay	-	-
Sugar beets	11	34	sand, reclaimed peat soil, clay	5 sources, 7 datapoints	10 datapoints for aboveground each based on four repetitions
Starch potato	5	20	reclaimed peat soil	-	-
Seed potato	4	8	reclaimed peat soil, clay	-	-
Ware potato	13	46	sand, reclaimed peat soil, clay	4 sources, 4 datapoints	-
Silage maize	16	43	sand, clay	2 sources, 8 datapoints	-
Grain maize	6	12	sand	1 source, 1 datapoint	-
Seed onion	3	10	sand, reclaimed peat soil	-	-
Grass seed – English ryegrass 1st year	5	20	clay	-	-
Grass seed – English ryegrass 2nd year	5	20	clay	-	-

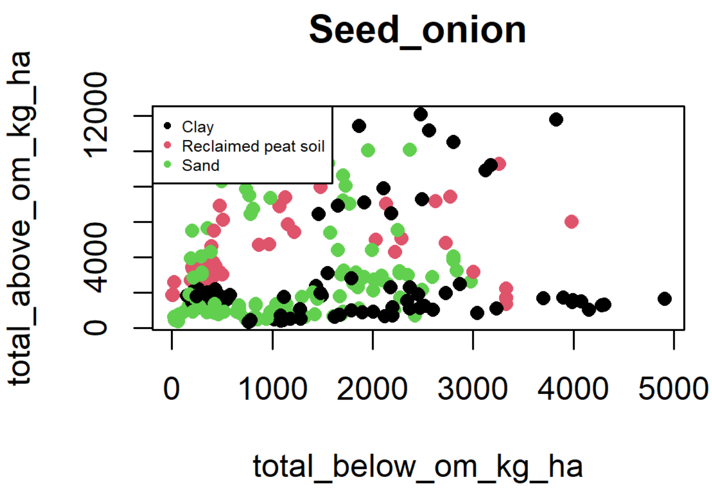
Appendix 2: (E)OM

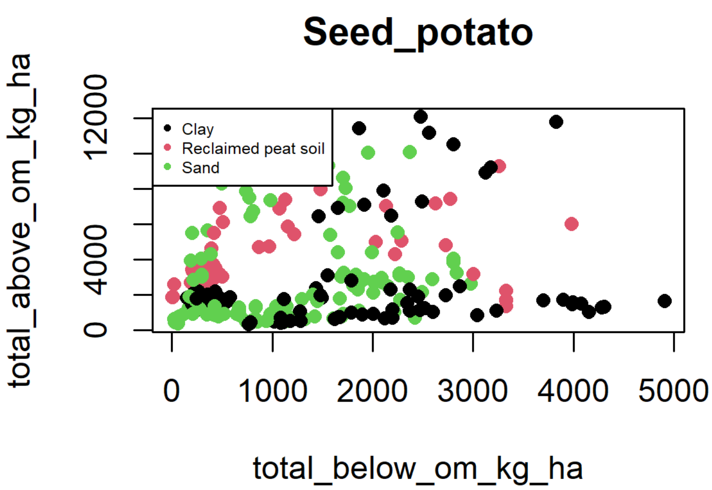
6.1 Plots of aboveground OM vs belowground OM

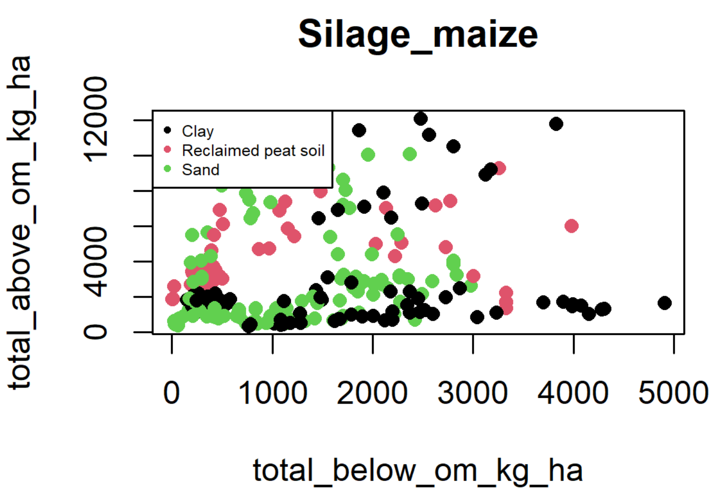


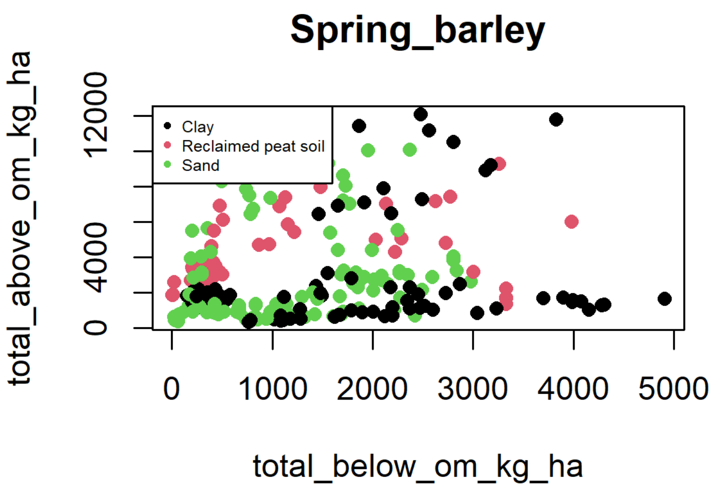


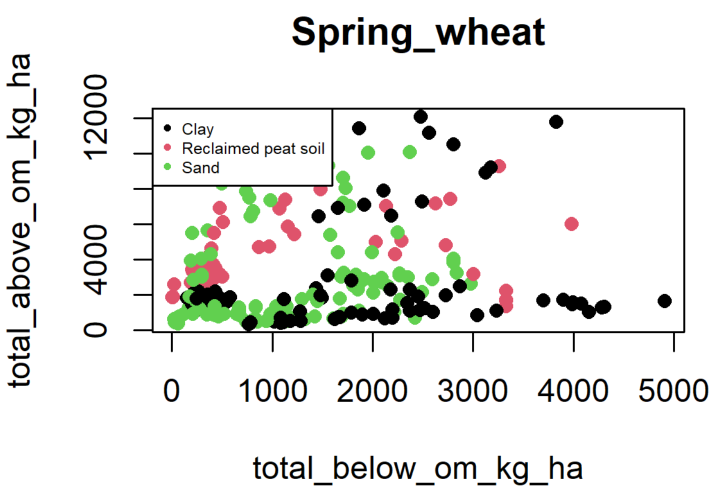


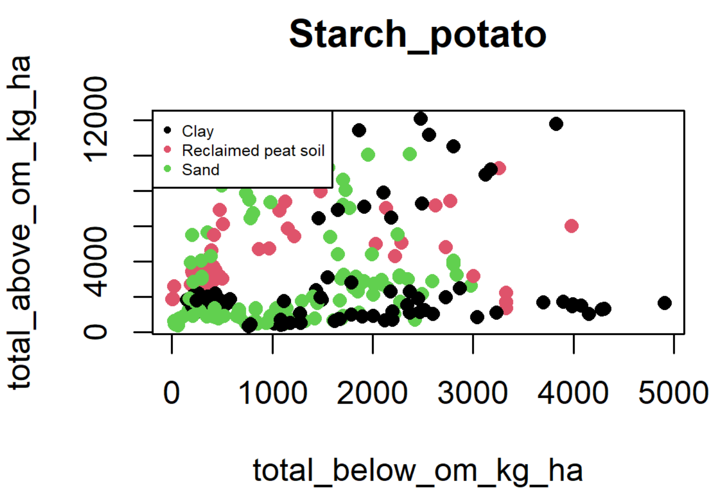

Seed_onion
Clay
Reclaimed peat soil
Sand
total_above_om_kg_ha
0
4000
12000
0
1000
2000
3000
4000
5000
total_below_om_kg_ha

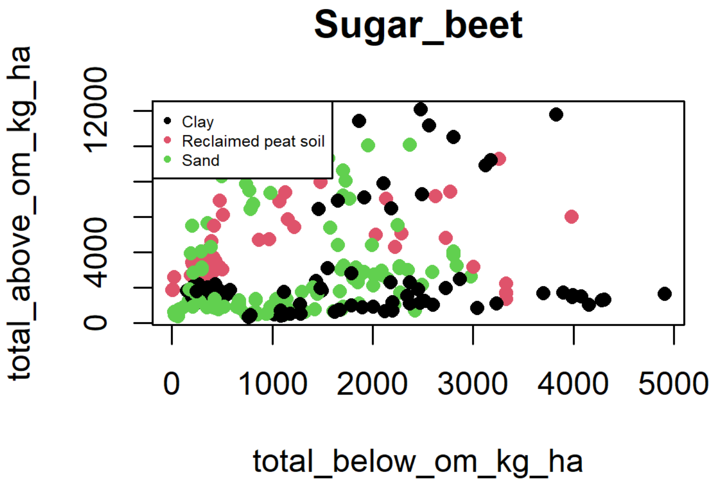

Seed_potato
Clay
Reclaimed peat soil
Sand
total_above_om_kg_ha
0
4000
12000
0
1000
2000
3000
4000
5000
total_below_om_kg_ha

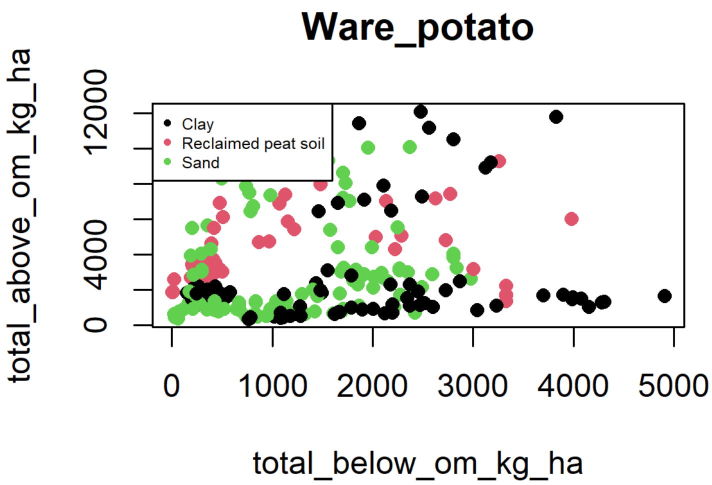

Silage_maize
Clay
Reclaimed peat soil
Sand
total_above_om_kg_ha
0
4000
12000
0
1000
2000
3000
4000
5000
total_below_om_kg_ha

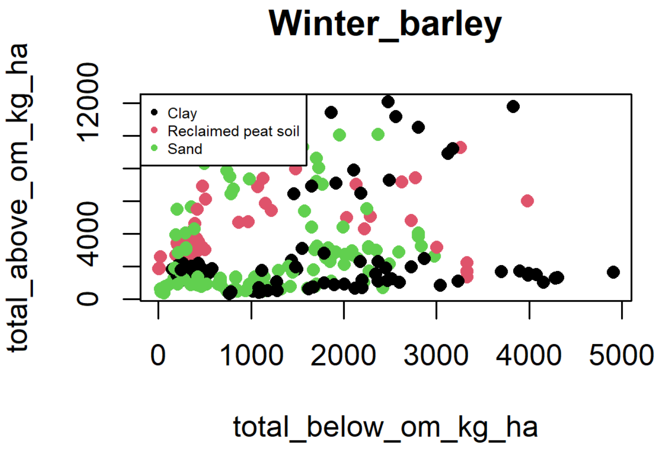

Spring_barley
total_above_om_kg_ha
0
4000
12000
Clay
Reclaimed peat soil
Sand
0
1000
2000
3000
4000
5000
total_below_om_kg_ha

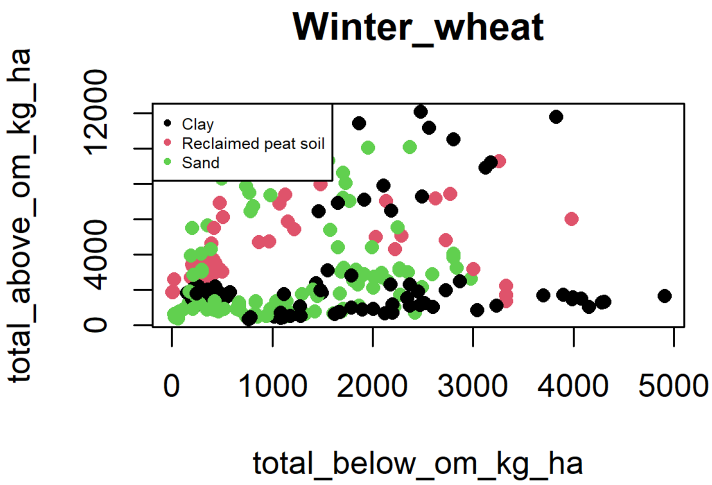

Spring_wheat
total_above_om_kg_ha
0
4000
12000
Clay
Reclaimed peat soil
Sand
0
1000
2000
3000
4000
5000
total_below_om_kg_ha


Starch_potato
total_above_om_kg_ha
0
4000
12000
Clay
Reclaimed peat soil
Sand
0
1000
2000
3000
4000
5000
total_below_om_kg_ha


Sugar_beet
total_above_om_kg_ha
0
4000
12000
Clay
Reclaimed peat soil
Sand
0
1000
2000
3000
4000
5000
total_below_om_kg_ha

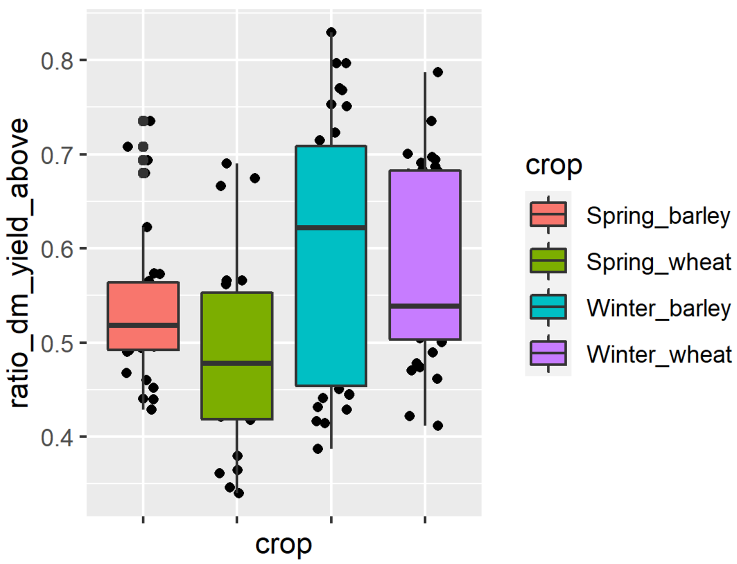

Ware_potato
total_above_om_kg_ha
0
4000
12000
Clay
Reclaimed peat soil
Sand
0
1000
2000
3000
4000
5000
total_below_om_kg_ha





6.2 Cereals - general results

Harvest index

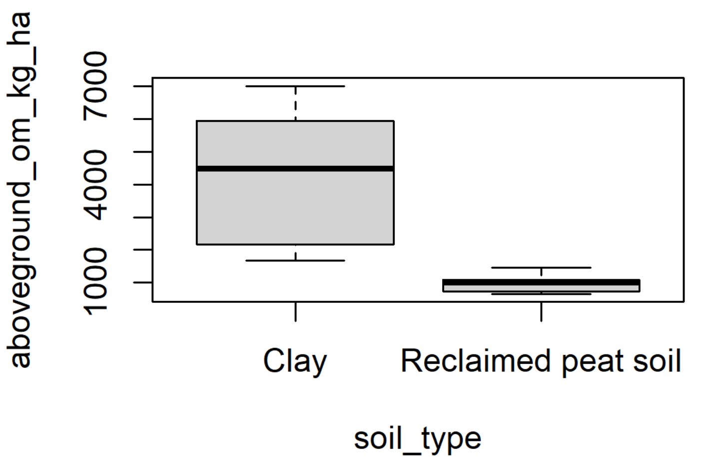


This graph only includes the entries of which both the yield and the whole aboveground biomass was available.

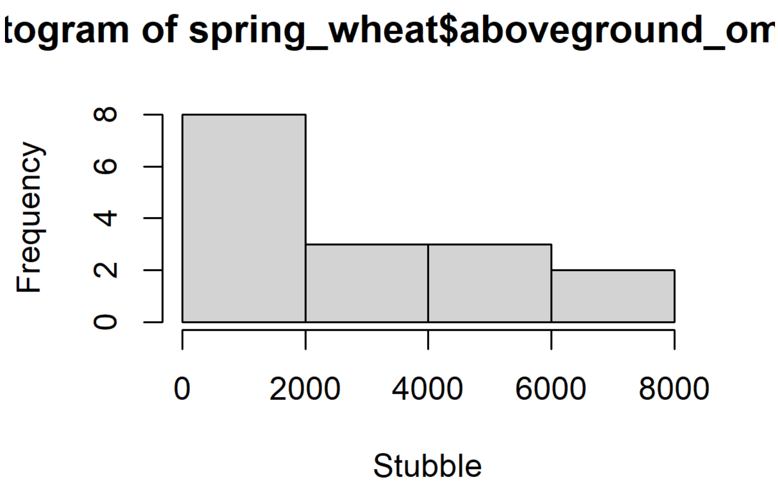
6.3 Spring wheat

Stubble

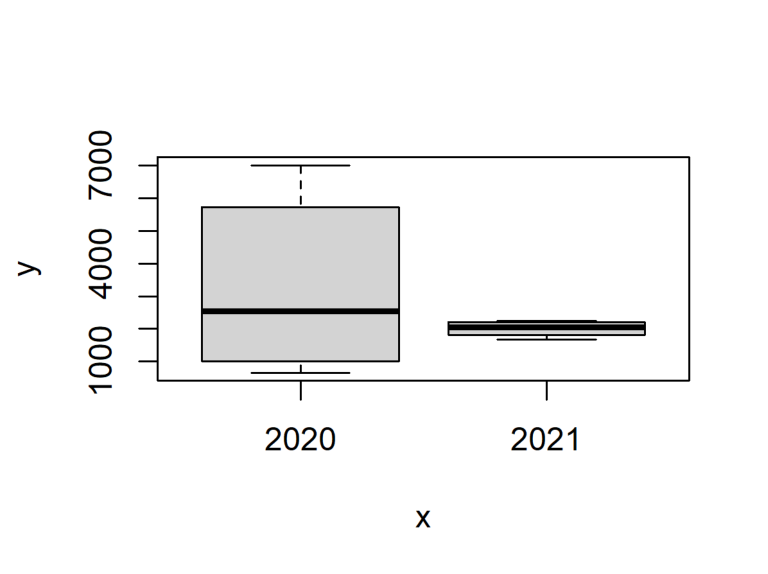
```
# Soil type
```



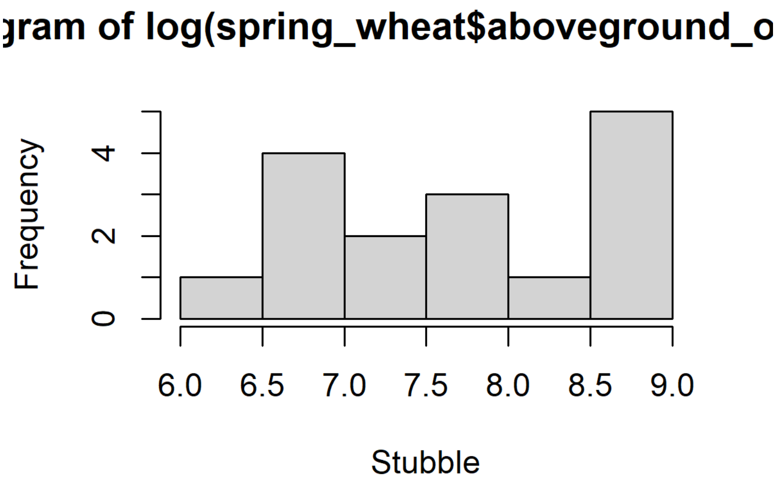

```
# Distribution and clean up outliers
```



Visual check

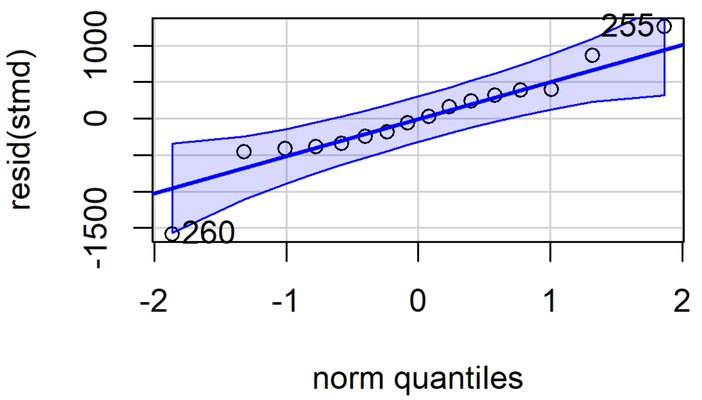


Log histogram




```
# Linear model analysis
stmd<-lm(aboveground_om_kg_ha ~ year + soil_type + cultivar_variety, weights=weights_above, data=spring_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: aboveground_om_kg_ha
                 Df   Sum Sq  Mean Sq  F value    Pr(>F)
year              1  5097018  5097018   9.2419   0.01125 *
soil_type         1 64326682 64326682 116.6375 3.409e-07 ***
cultivar_variety  2  1023399   511699   0.9278   0.42427
Residuals        11  6066602   551509
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   1437 284 11      813     2062

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubble <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
```

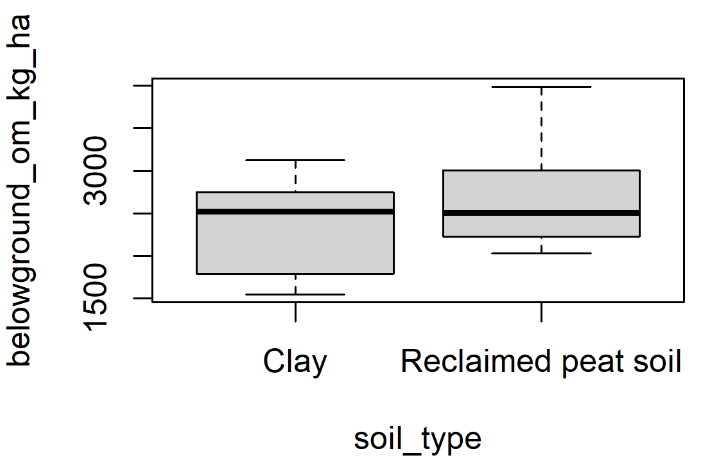
```
1       emmean  SE df lower.CL upper.CL
overall   1437 284 11      813     2062

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



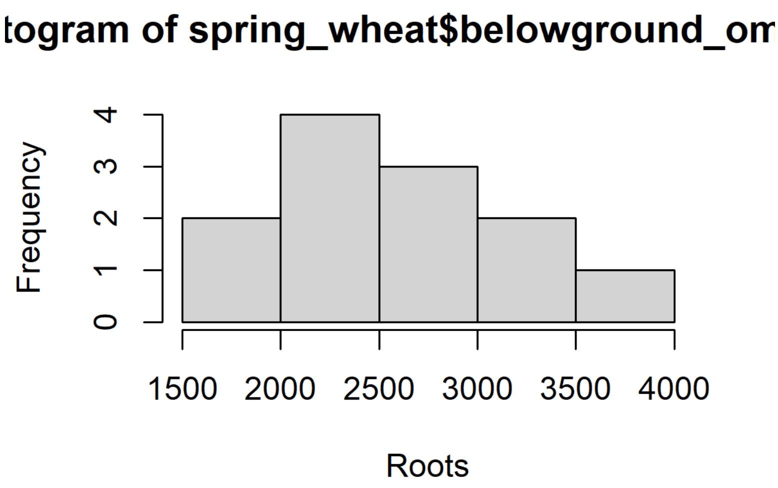

```
260 255
 12   7

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.9425, p-value = 0.3807
```

Belowground

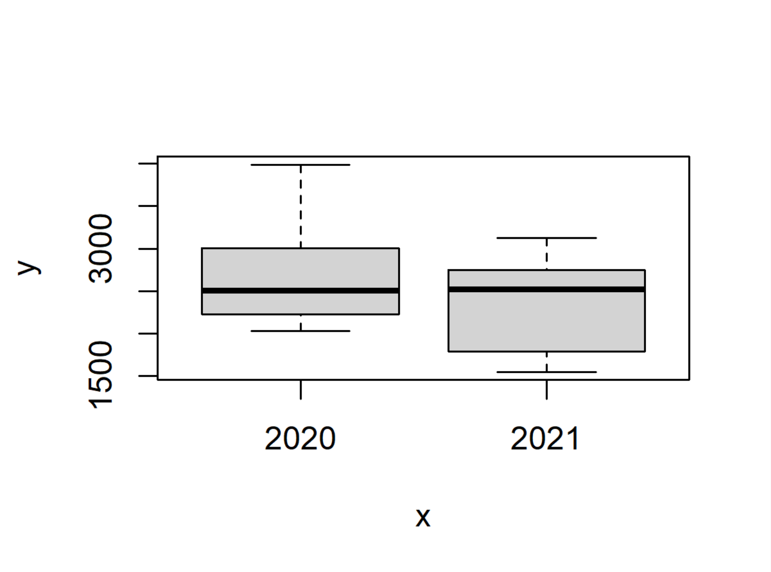
```
# Soil type
```



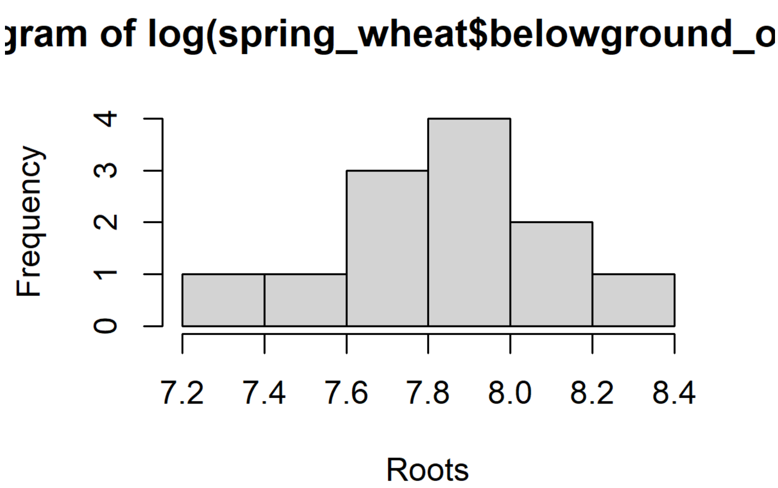

```
# Distribution and clean up outliers
```



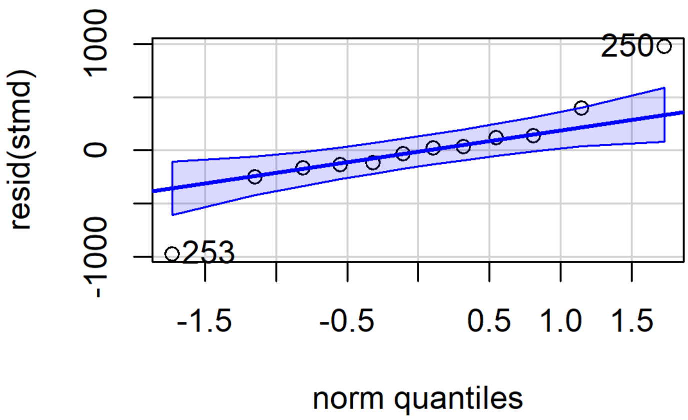
Visual check



Log histogram



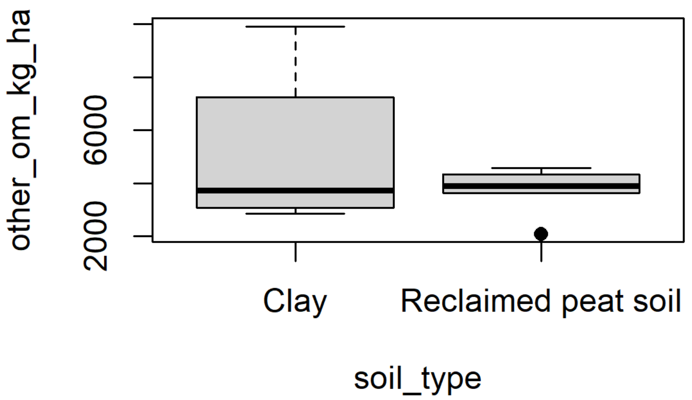
```
# Linear model analysis
stmd<-lm(belowground_om_kg_ha ~ soil_type + cultivar_variety , weights=weights_below, data=spring_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: belowground_om_kg_ha
                 Df  Sum Sq Mean Sq F value Pr(>F)
soil_type         1  333998  333998  1.0516 0.3393
cultivar_variety  3 2131692  710564  2.2373 0.1714
Residuals         7 2223241  317606
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   2569 186  7     2128     3010

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```



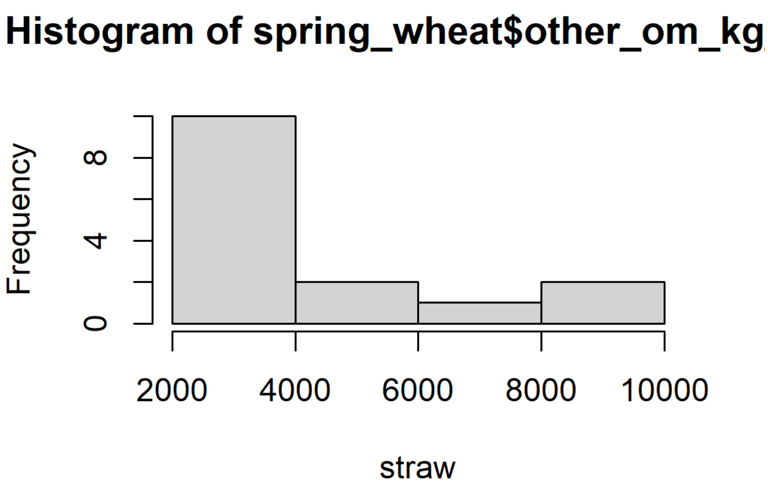

```
250 253
  2   5
    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.89701, p-value = 0.1451
```

Straw

```
# Soil type
```

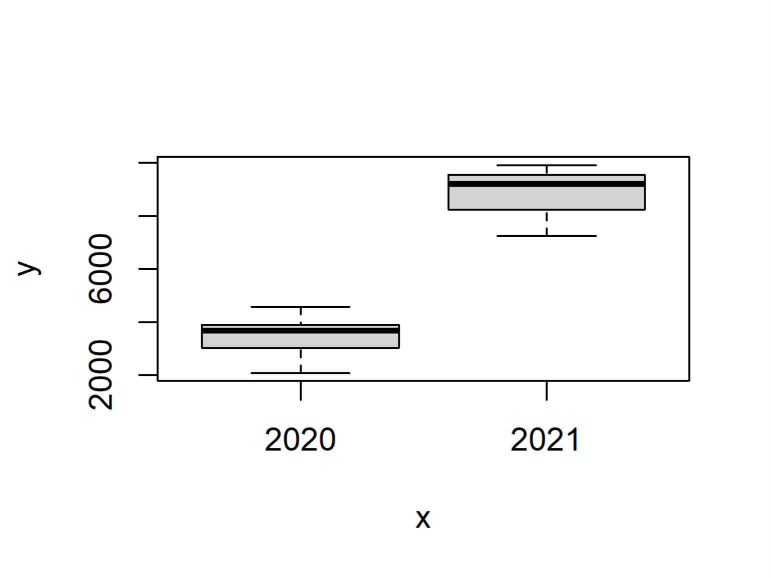


Distribution and clean up outliers

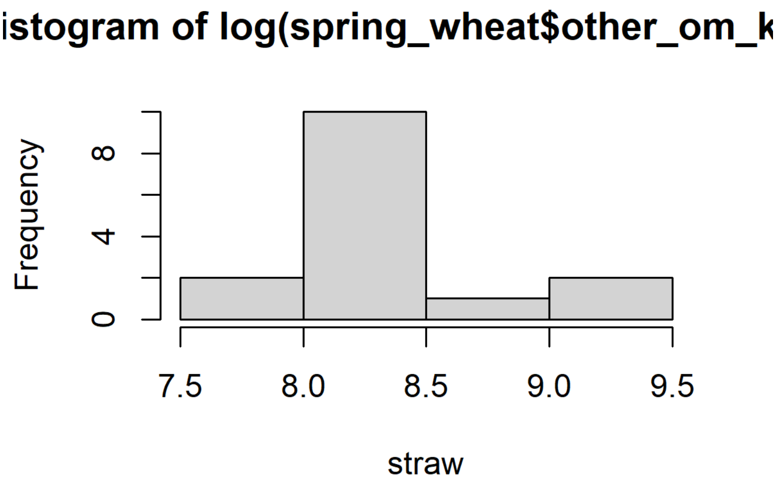


One outlier was removed

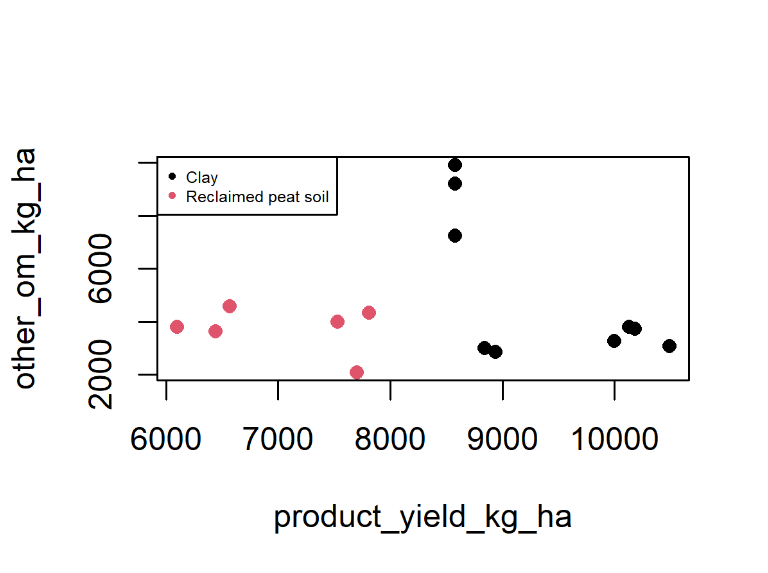
```
# Visual check
```




```
# Log histogram
```

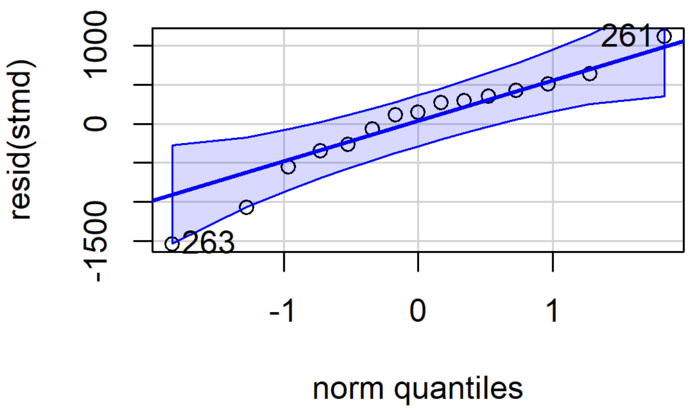


```
# Plot of yield vs aboveground biomass
```




```
# Model of straw biomass vs yield (total not always available)
lm_sw <- lm(other_om_kg_ha ~ product_yield_kg_ha, data=spring_wheat, weights=weights_above)
summary(lm_sw)

Call:
lm(formula = other_om_kg_ha ~ product_yield_kg_ha, data = spring_wheat,
    weights = weights_above)

Residuals:
    Min      1Q  Median      3Q     Max
-2519.2 -1309.1  -757.0  -179.4  5345.0

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         4994.86071 3917.09803   1.275    0.225
product_yield_kg_ha   -0.05077    0.45865  -0.111    0.914

Residual standard error: 2415 on 13 degrees of freedom
  (7 observations deleted due to missingness)
Multiple R-squared:  0.0009416, Adjusted R-squared:  -0.07591
F-statistic: 0.01225 on 1 and 13 DF,  p-value: 0.9136
# Linear model analysis
stmd<-lm(other_om_kg_ha ~ year + soil_type + cultivar_variety , weights=weights_above,data=spring_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: other_om_kg_ha
                 Df   Sum Sq  Mean Sq  F value    Pr(>F)
year              1 66872249 66872249 104.1034 1.322e-06 ***
soil_type         1   607448   607448   0.9456    0.3538
cultivar_variety  2  1992275   996138   1.5507    0.2591
Residuals        10  6423639   642364
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   6138 327 10     5408     6867

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_straw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
```

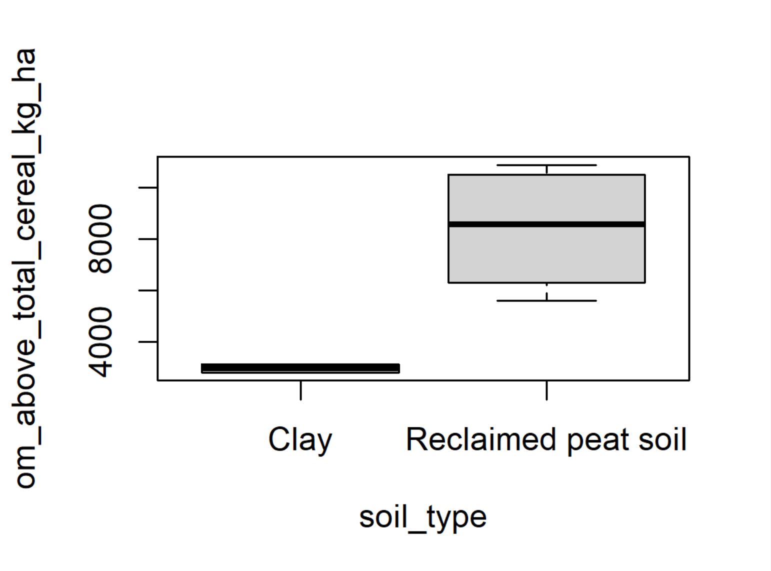
```
1       emmean  SE df lower.CL upper.CL
overall   6138 327 10     5408     6867

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



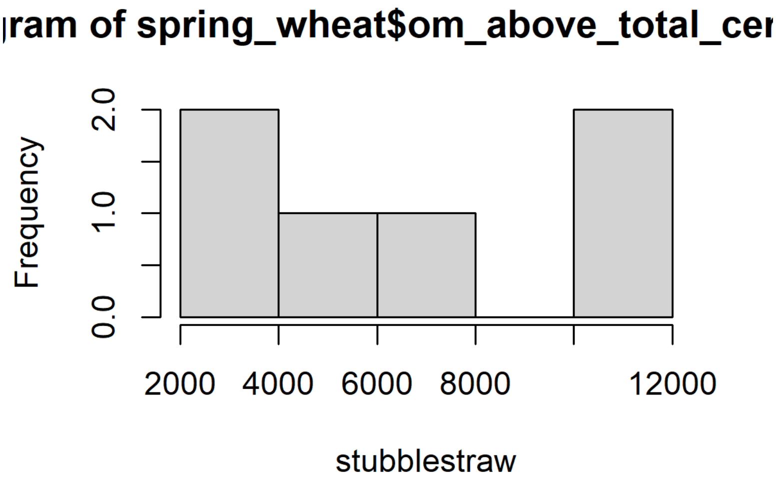

```
263 261
 14  13

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.94487, p-value = 0.4476
```

Stubble + Straw

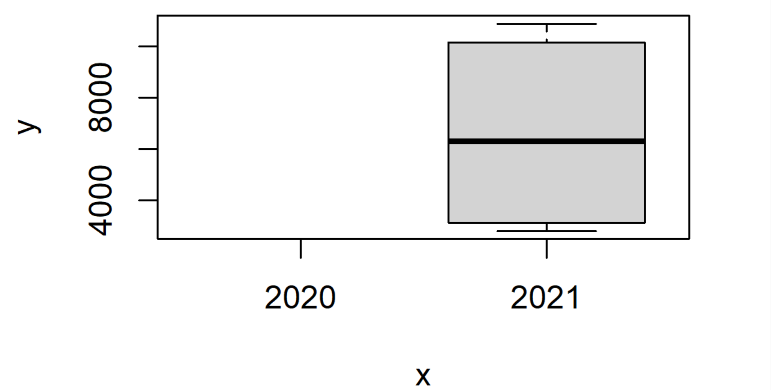
```
# Soil type
```



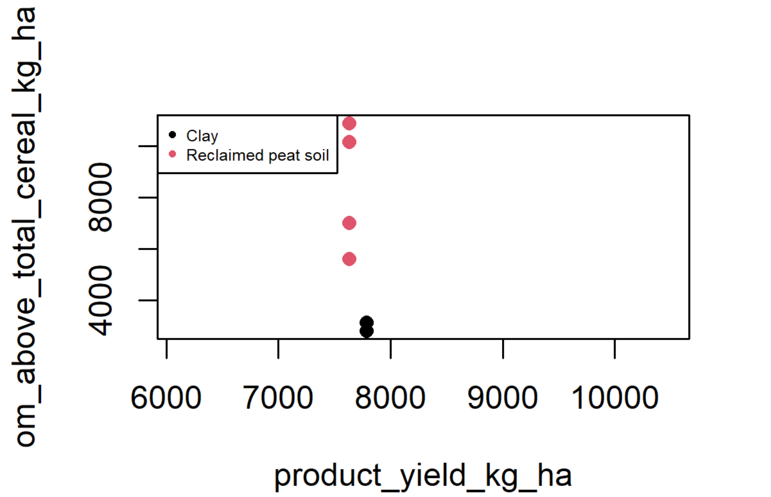

```
# Distribution and clean up outliers
```



Visual check

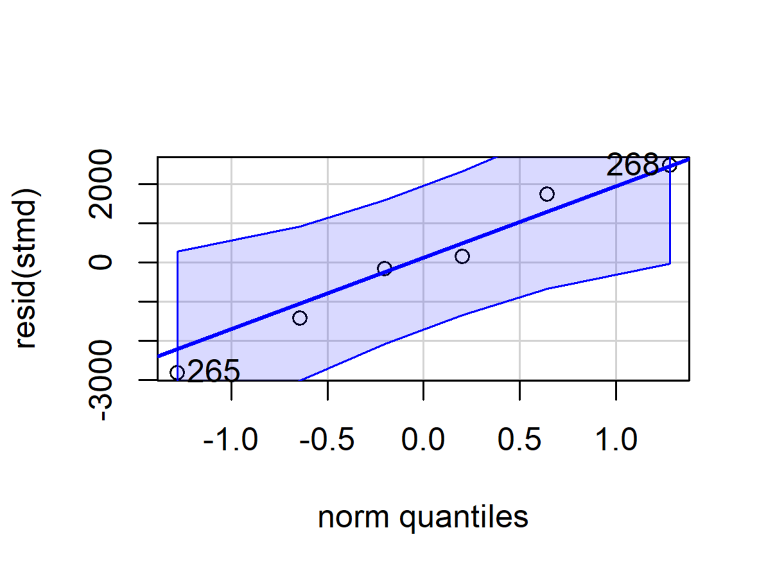


Plot of yield vs aboveground biomas



```
# Model of aboveground biomass vs yield
lm_sw <- lm(om_above_total_cereal_kg_ha ~ product_yield_kg_ha, data=spring_wheat, weights=weights_above)
summary(lm_sw)

Call:
lm(formula = om_above_total_cereal_kg_ha ~ product_yield_kg_ha,
    data = spring_wheat, weights = weights_above)

Residuals:
    265     266     267     268     269     270
-2806.0  1747.2 -1412.3  2471.2   153.9  -153.9

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         278254.09   94382.97   2.948   0.0420 *
product_yield_kg_ha    -35.35      12.28  -2.879   0.0451 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2184 on 4 degrees of freedom
  (16 observations deleted due to missingness)
Multiple R-squared:  0.6744,    Adjusted R-squared:  0.593
F-statistic: 8.286 on 1 and 4 DF,  p-value: 0.04508
# Linear model analysis
stmd<-lm(om_above_total_cereal_kg_ha ~ cultivar_variety , weights=weights_above, data=spring_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: om_above_total_cereal_kg_ha
                 Df   Sum Sq  Mean Sq F value  Pr(>F)
cultivar_variety  1 39512624 39512624  8.2858 0.04508 *
Residuals         4 19074943  4768736
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   5678 946  4     3052     8303

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
EMM_stubblestraw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   5678 946  4     3052     8303
```

```
Results are averaged over the levels of: cultivar_variety
```




```
Confidence level used: 0.95
265 268
  1   4

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.97256, p-value = 0.9092
```

Summary

```
#Stubble

## Number of observations
sum(!is.na(spring_wheat$aboveground_om_kg_ha))
 16
## IQR
summary(spring_wheat$aboveground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
 658.2  1077.5  2053.4  2980.9  5378.3  7000.5       6 
# Roots

## Number of observations
sum(!is.na(spring_wheat$belowground_om_kg_ha))
 12
## IQR
summary(spring_wheat$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   1552    2177    2520    2543    2814    3983      10 
# Straw

## Number of observations
sum(!is.na(spring_wheat$other_om_kg_ha))
 15
## IQR
summary(spring_wheat$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   2085    3166    3799    4567    4450    9904       7 
# Stubble + straw

## Number of observations
sum(!is.na(spring_wheat$om_above_total_cereal_kg_ha))
 6
## IQR
summary(spring_wheat$om_above_total_cereal_kg_ha, na.rm=TRUE)
```

```
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   2802    3731    6290    6585    9357   10871      16 
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(EMM_stubble + EMM_straw, EMM_stubblestraw)
weight <- c(min(sum(!is.na(spring_wheat$aboveground_om_kg_ha)), sum(!is.na(spring_wheat$other_om_kg_ha))), sum(!is.na(spr
ing_wheat$om_above_total_cereal_kg_ha)))
weighted.mean(values, weight, na.rm=TRUE)
 7032.754
```

Statistical testing

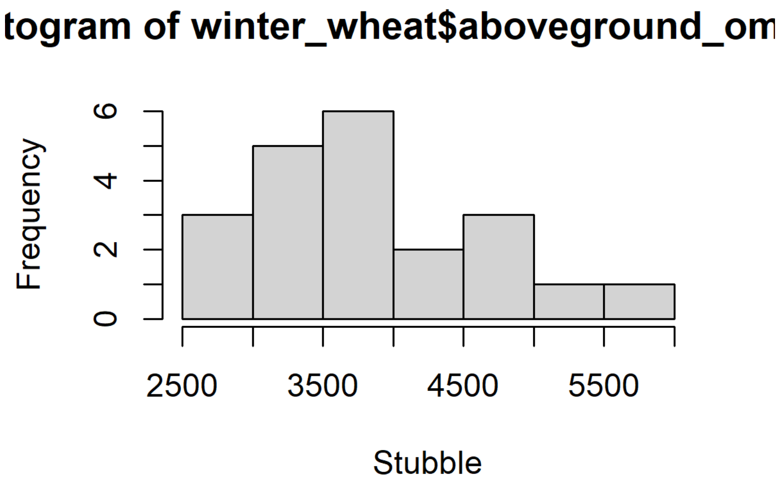
```
    Shapiro-Wilk normality test

data:  log(spring_wheat$aboveground_om_kg_ha)
W = 0.91784, p-value = 0.1557

    One Sample t-test

data:  log(spring_wheat$aboveground_om_kg_ha) * 0.3
t = -67.582, df = 15, p-value < 2.2e-16
alternative hypothesis: true mean is not equal to 6.44572
95 percent confidence interval:
 2.180708 2.441507
sample estimates:
mean of x 
 2.311108 

    Shapiro-Wilk normality test

data:  spring_wheat$belowground_om_kg_ha
W = 0.96839, p-value = 0.8932

    One Sample t-test

data:  spring_wheat$belowground_om_kg_ha * 0.35
t = 6.067, df = 11, p-value = 8.11e-05
alternative hypothesis: true mean is not equal to 490
95 percent confidence interval:
  745.0228 1035.4017
sample estimates:
mean of x 
 890.2123 

    Shapiro-Wilk normality test

data:  log(spring_wheat$other_om_kg_ha)
W = 0.89275, p-value = 0.07382

    One Sample t-test

data:  log(spring_wheat$other_om_kg_ha) * 0.3
t = -130.14, df = 14, p-value < 2.2e-16
alternative hypothesis: true mean is not equal to 6.866933
95 percent confidence interval:
 2.426917 2.570892
sample estimates:
mean of x 
 2.498905 

    Shapiro-Wilk normality test
```

```
data:  spring_wheat$om_above_total_cereal_kg_ha
W = 0.90619, p-value = 0.4118

    One Sample t-test

data:  spring_wheat$om_above_total_cereal_kg_ha * 0.3
t = 0.91937, df = 5, p-value = 0.4001
alternative hypothesis: true mean is not equal to 1590
95 percent confidence interval:
  897.7455 3053.1302
sample estimates:
mean of x
 1975.438
```

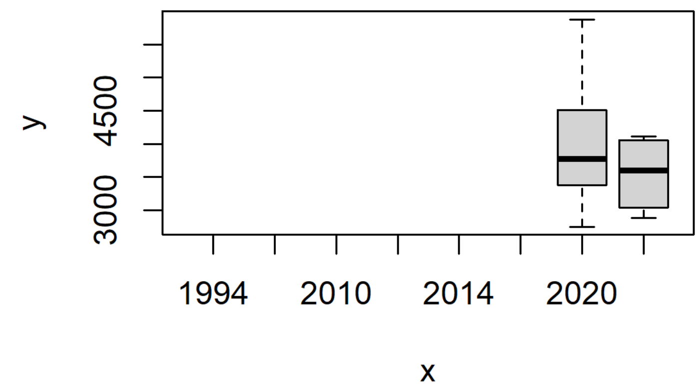
6.4 Winter wheat

Stubble

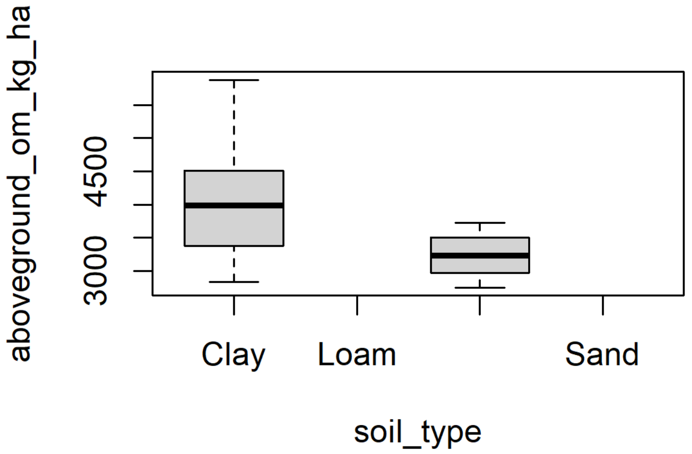
```
# Distribution and clean up outliers
```



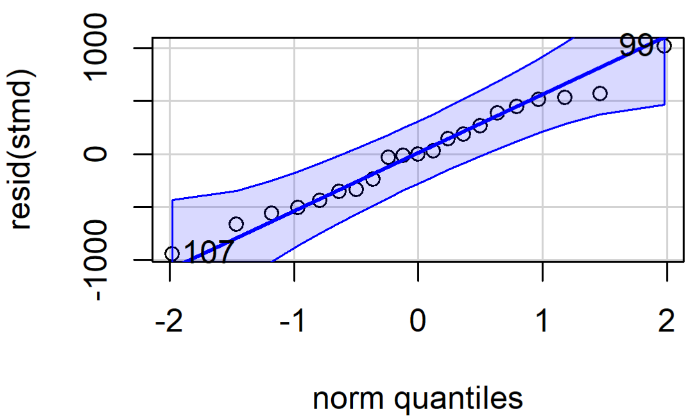

```
# Visual check by year
```



```
# Soil type
```



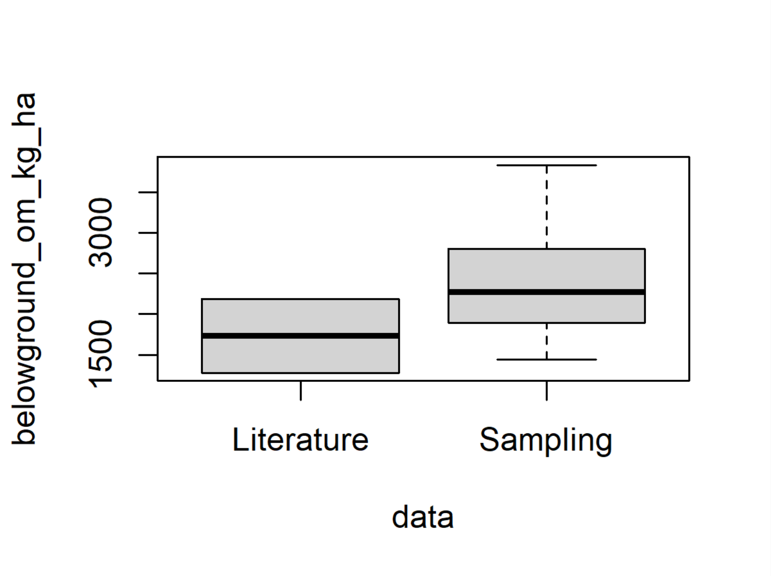

```
# Linear model analysis
stmd<-lm(aboveground_om_kg_ha ~ year + soil_type + cultivar_variety,weights=weights_above, data=winter_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: aboveground_om_kg_ha
                 Df  Sum Sq Mean Sq F value   Pr(>F)
year              1  521760  521760  1.6406 0.219692
soil_type         1 2652333 2652333  8.3399 0.011268 *
cultivar_variety  3 5564766 1854922  5.8326 0.007562 **
Residuals        15 4770412  318027
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   3547 285 15     2939     4154

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubble <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   3547 285 15     2939     4154

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



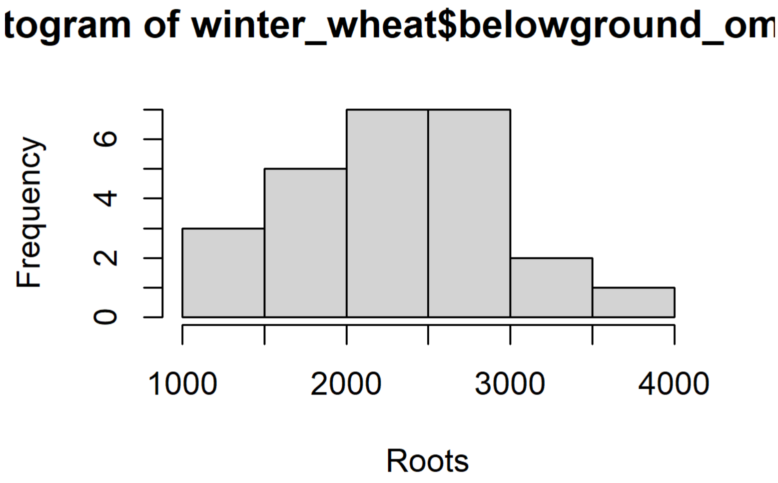

```
99 107
 7  14

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.091764, p-value = 0.9873
alternative hypothesis: two-sided
```

Belowground

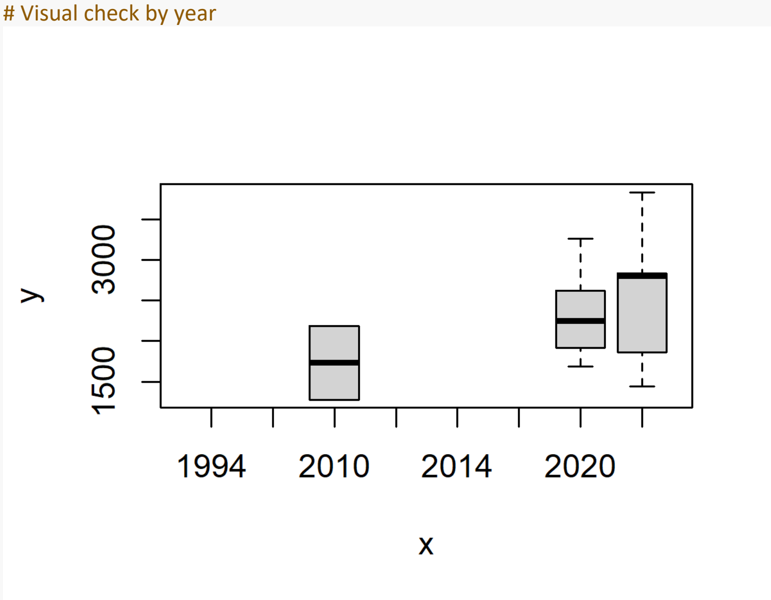
```
# Literature check
```



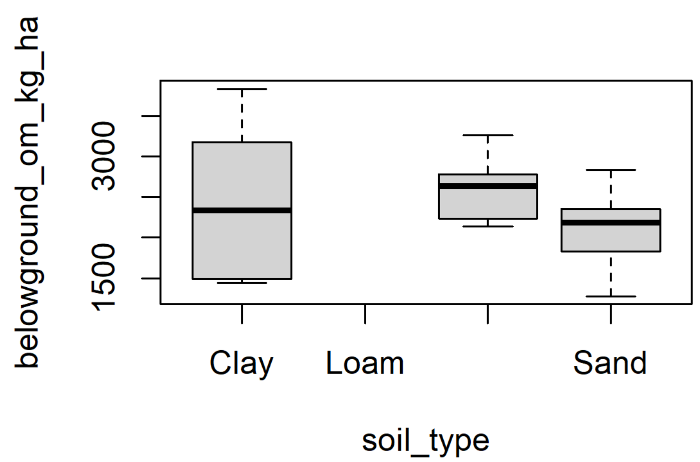

```
# Distribution and clean up outliers
```



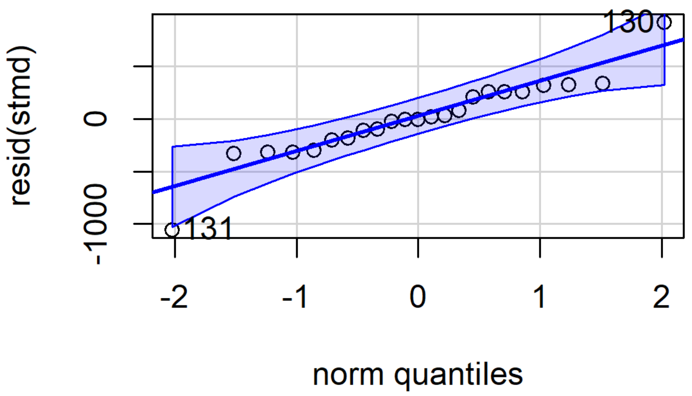

```
# Visual check by year
```




```
# Soil type
```



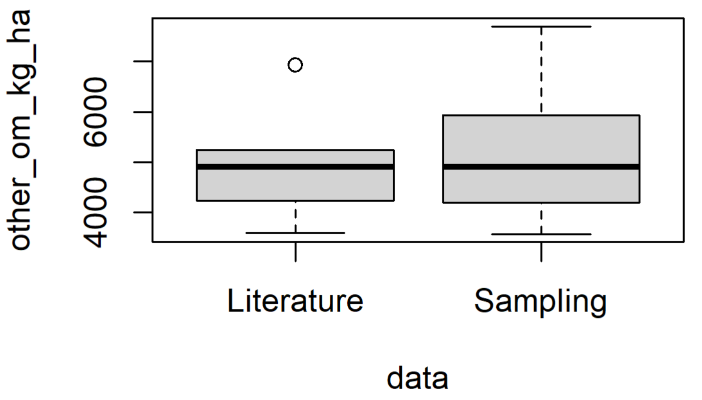
```
# Linear model analysis
stmd<-lm(belowground_om_kg_ha ~ soil_type + cultivar_variety , weights=weights_below,data=winter_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: belowground_om_kg_ha
                 Df  Sum Sq Mean Sq F value   Pr(>F)
soil_type         2  571962  285981  1.5193 0.248820
cultivar_variety  4 4535328 1133832  6.0235 0.003735 **
Residuals        16 3011738  188234
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   2491 121 16     2234     2747

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```



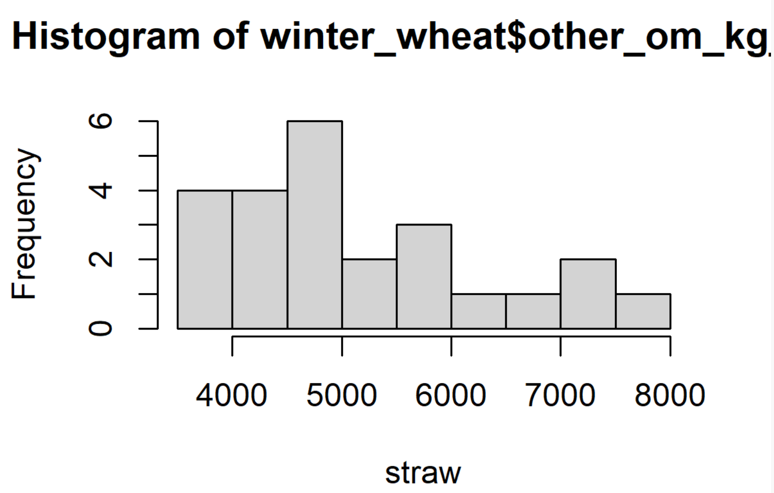

```
131 130
 22  21

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.14116, p-value = 0.7492
alternative hypothesis: two-sided
```

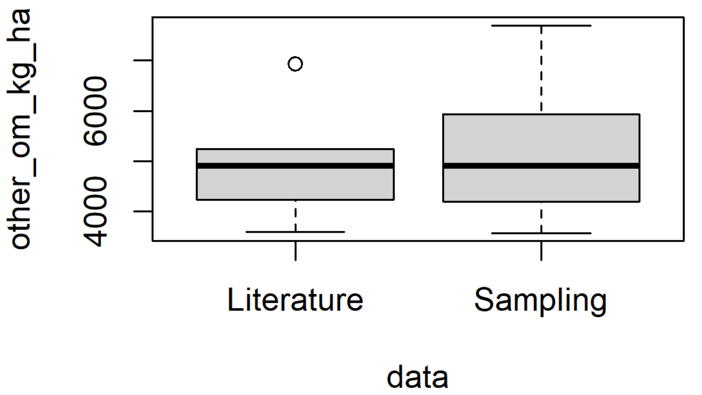
Straw

```
# Literature check
```

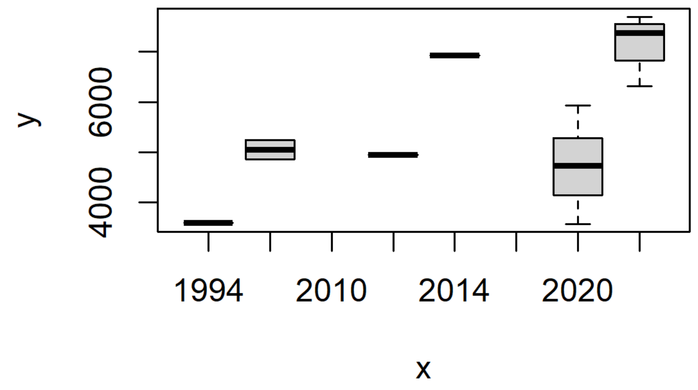


Distribution and clean up outliers

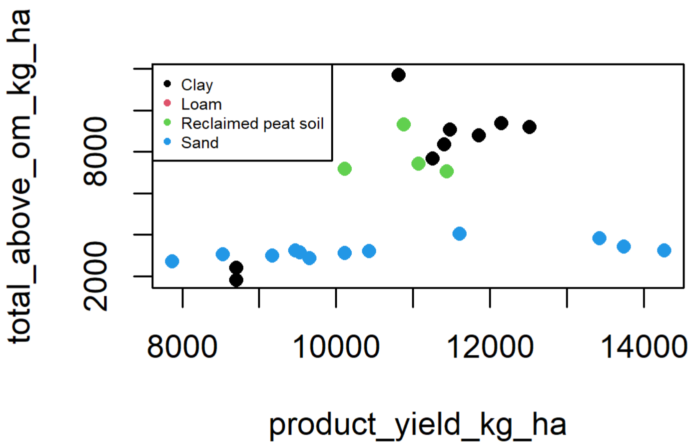




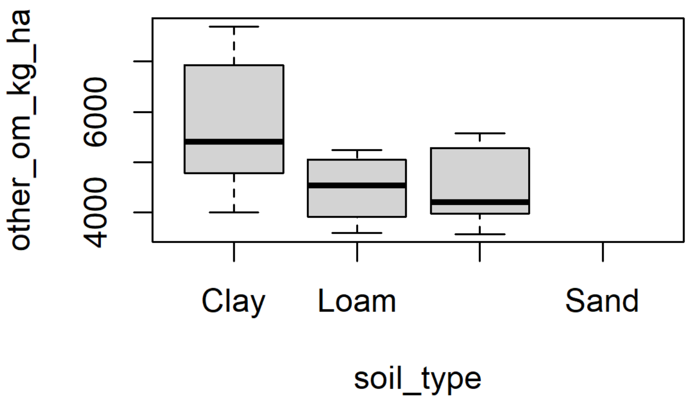
Visual check



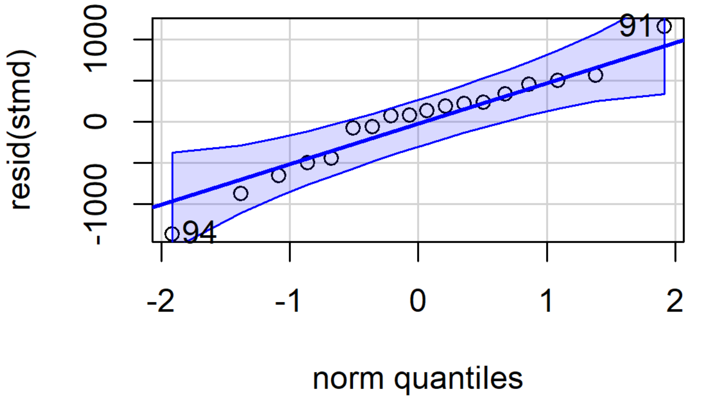
Plot yield vs aboveground biomass



Soil type



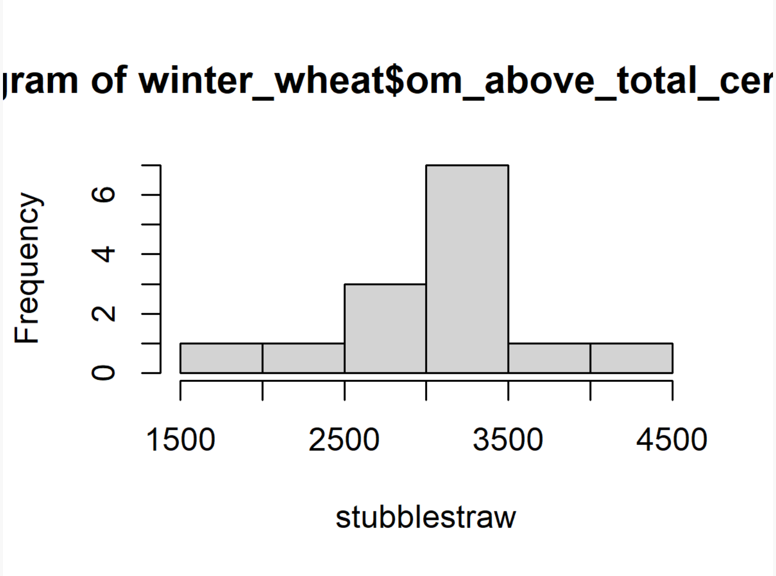

```
# Linear model analysis
stmd<-lm(other_om_kg_ha ~ year + soil_type + cultivar_variety , weights=weights_above,data=winter_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: other_om_kg_ha
                 Df   Sum Sq  Mean Sq F value    Pr(>F)
year              1 18943674 18943674 38.6567 4.468e-05 ***
soil_type         1   638133   638133  1.3022    0.2761
cultivar_variety  3  1544441   514814  1.0505    0.4059
Residuals        12  5880586   490049
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   5858 303 12     5197     6518

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_straw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   5858 303 12     5197     6518

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



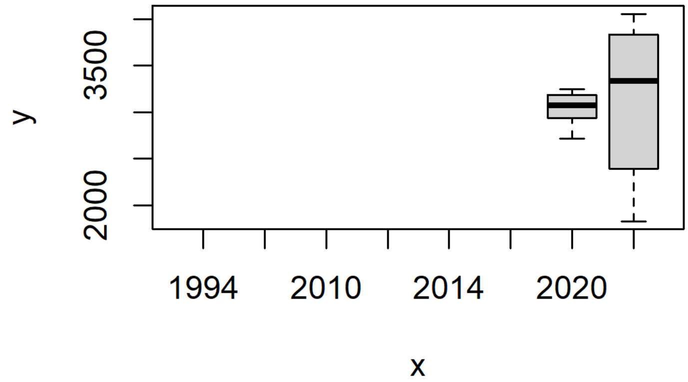

```
94 91
 4  1

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.17195, p-value = 0.602
alternative hypothesis: two-sided
```

Stubble + Straw

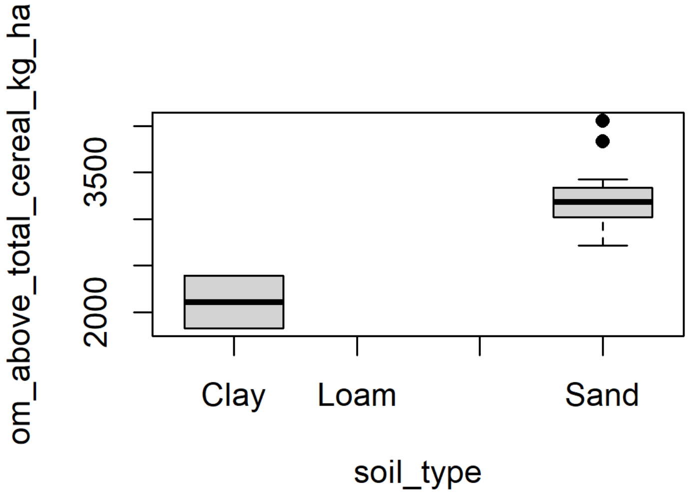
```
# Distribution and clean up outliers
```



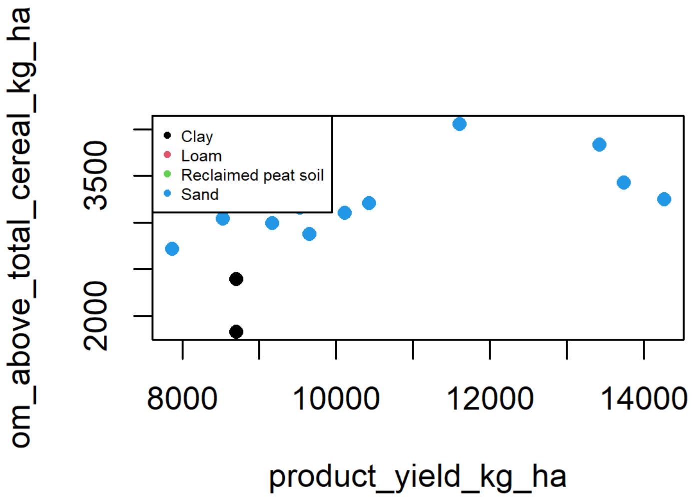

```
# Visual check
```




```
# Soil type
```

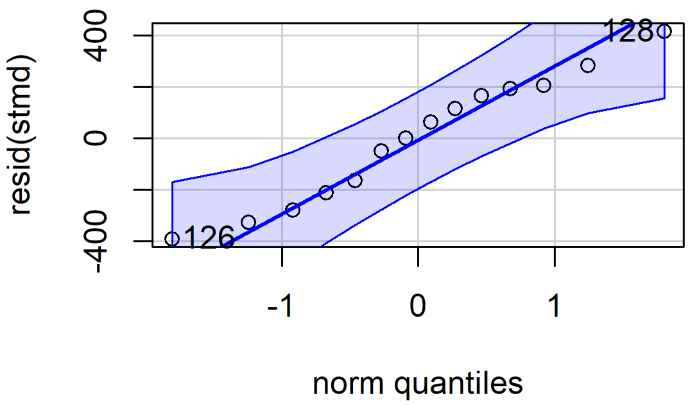



```
# Plot of yield vs aboveground biomass
```




```
lm_sw <- lm(om_above_total_cereal_kg_ha ~ product_yield_kg_ha, data=winter_wheat, weights=weights_above)
summary(lm_sw)

Call:
lm(formula = om_above_total_cereal_kg_ha ~ product_yield_kg_ha,
    data = winter_wheat, weights = weights_above)

Residuals:
    Min      1Q  Median      3Q     Max
-967.61 -191.63   92.86  229.26  762.01

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.313e+03  6.184e+02   2.123   0.0552 .
product_yield_kg_ha 1.702e-01  5.854e-02   2.908   0.0131 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 438.2 on 12 degrees of freedom
  (37 observations deleted due to missingness)
Multiple R-squared:  0.4133,    Adjusted R-squared:  0.3644
F-statistic: 8.454 on 1 and 12 DF,  p-value: 0.01314
# Linear model analysis
stmd<-lm(om_above_total_cereal_kg_ha ~ soil_type + cultivar_variety , weights=weights_above, data=winter_wheat)
print(anova(stmd))
Analysis of Variance Table

Response: om_above_total_cereal_kg_ha
                 Df  Sum Sq Mean Sq F value    Pr(>F)
soil_type         1 2194084 2194084  30.579 0.0001781 ***
cultivar_variety  1  943717  943717  13.153 0.0039799 **
Residuals        11  789264   71751
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   2873 116 11     2618     3128

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubblestraw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   2873 116 11     2618     3128
```

```
Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```




```
128 126
 14  12
   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.96439, p-value = 0.7941
```

Summary

```
# Stubble
sum(!is.na(winter_wheat$aboveground_om_kg_ha))
 21
## IQR
summary(winter_wheat$aboveground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   2751    3286    3777    3872    4126    5870      30
# Roots
sum(!is.na(winter_wheat$belowground_om_kg_ha))
 25
## IQR
summary(winter_wheat$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   1278    1862    2271    2333    2806    3829      26
# Straw
sum(!is.na(winter_wheat$other_om_kg_ha))
 24
## IQR
summary(winter_wheat$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   3576    4221    4905    5193    5851    7687      27
# Stubble + straw
sum(!is.na(winter_wheat$om_above_total_cereal_kg_ha))
 14
## IQR
summary(winter_wheat$om_above_total_cereal_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   1827    2905    3130    3079    3246    4050      37
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(EMM_stubble + EMM_straw, EMM_stubblestraw)
weight <- c(min(sum(!is.na(winter_wheat$aboveground_om_kg_ha)), sum(!is.na(winter_wheat$other_om_kg_ha))), sum(!is.na(wi
```

```
nter_wheat$om_above_total_cereal_kg_ha)))

weighted.mean(values, weight, na.rm=TRUE)
 6791.673
```

Statistical testing

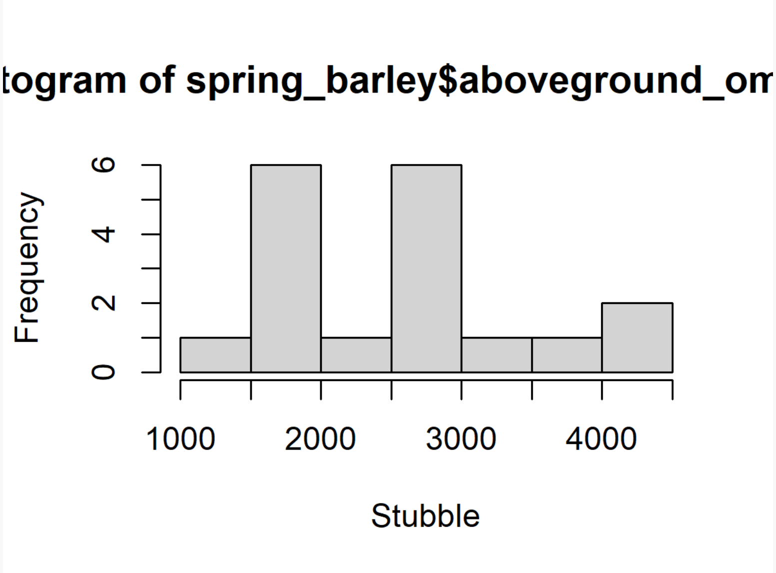
```
	Shapiro-Wilk normality test

data:  winter_wheat$aboveground_om_kg_ha
W = 0.94293, p-value = 0.2489

	One Sample t-test

data:  (winter_wheat$aboveground_om_kg_ha) * 0.3
t = 9.8811, df = 20, p-value = 3.867e-09
alternative hypothesis: true mean is not equal to 630
95 percent confidence interval:
 1049.407 1273.873
sample estimates:
mean of x 
  1161.64 

	Shapiro-Wilk normality test

data:  winter_wheat$belowground_om_kg_ha
W = 0.9745, p-value = 0.7593

	One Sample t-test

data:  winter_wheat$belowground_om_kg_ha * 0.35
t = 5.8818, df = 24, p-value = 4.56e-06
alternative hypothesis: true mean is not equal to 560
95 percent confidence interval:
 726.5036 906.5238
sample estimates:
mean of x 
 816.5137 

	Shapiro-Wilk normality test

data:  log(winter_wheat$other_om_kg_ha)
W = 0.9529, p-value = 0.3128

	One Sample t-test

data:  log(winter_wheat$other_om_kg_ha) * 0.3
t = -282.45, df = 23, p-value < 2.2e-16
alternative hypothesis: true mean is not equal to 6.44572
95 percent confidence interval:
 2.530615 2.587547
sample estimates:
mean of x 
 2.559081 

	Shapiro-Wilk normality test

data:  winter_wheat$om_above_total_cereal_kg_ha
W = 0.949, p-value = 0.5453

	One Sample t-test
```

```
data:  winter_wheat$om_above_total_cereal_kg_ha * 0.3
t = -15.804, df = 13, p-value = 7.239e-10
alternative hypothesis: true mean is not equal to 1620
95 percent confidence interval:
 828.3674 1018.7720
sample estimates:
mean of x
 923.5697
```

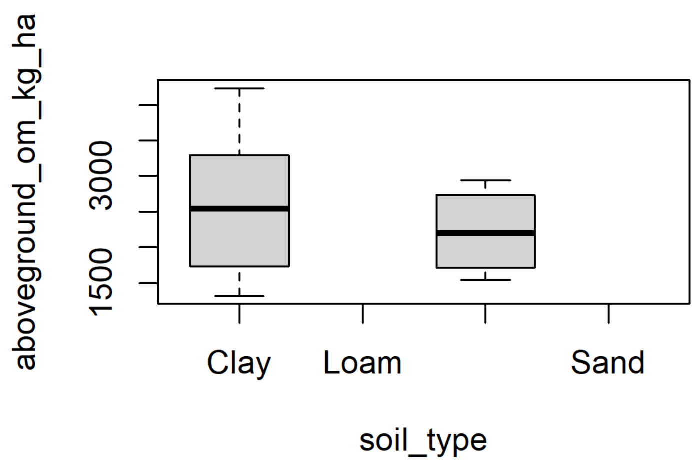
6.5 Spring barley

Stubble

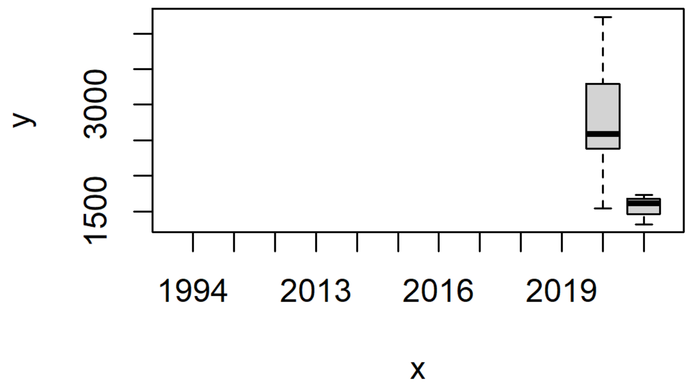
```
# Distribution and clean up outliers
```



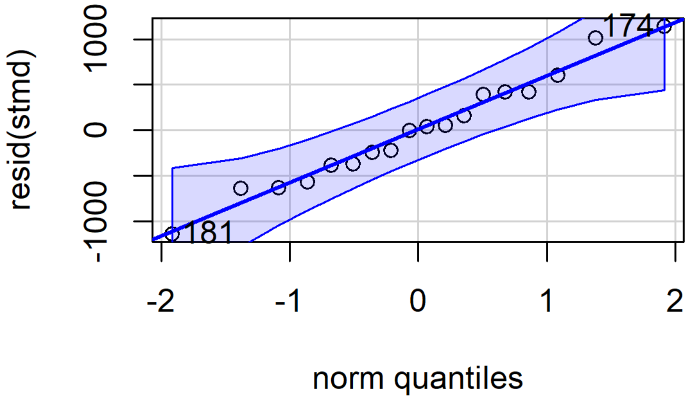

```
# Soil type
```




```
# Visual check
```



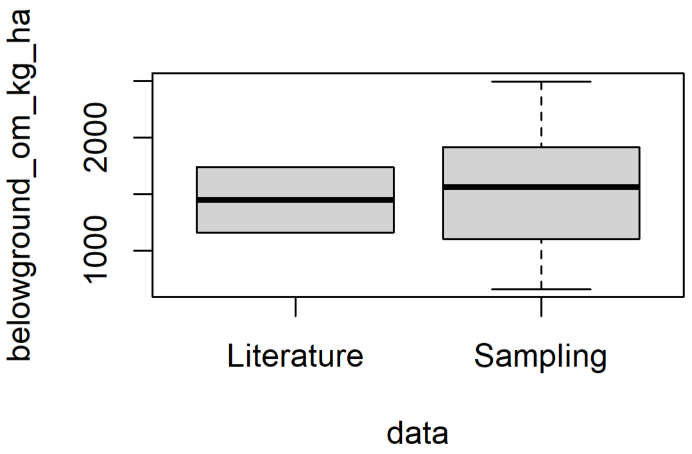

```
# Linear model analysis
stmd<-lm(aboveground_om_kg_ha ~ year + soil_type + cultivar_variety, weights=weights_above, data=spring_barley)
print(anova(stmd))
Analysis of Variance Table

Response: aboveground_om_kg_ha
                 Df  Sum Sq Mean Sq F value   Pr(>F)
year              1 4370550 4370550  9.3764 0.009086 **
soil_type         1 1591430 1591430  3.4142 0.087512 .
cultivar_variety  2  881339  440670  0.9454 0.413681
Residuals        13 6059576  466121
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   1895 253 13     1350     2441

Results are averaged over the levels of: soil_type, cultivar_variety, year
Confidence level used: 0.95
EMM_stubble <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   1895 253 13     1350     2441

Results are averaged over the levels of: soil_type, cultivar_variety, year
Confidence level used: 0.95
```



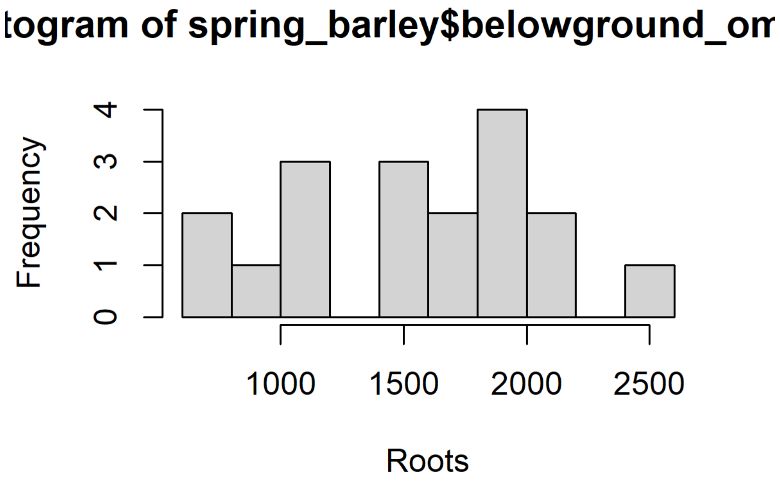

```
181 174
 12   5

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.97929, p-value = 0.9424
```

Belowground

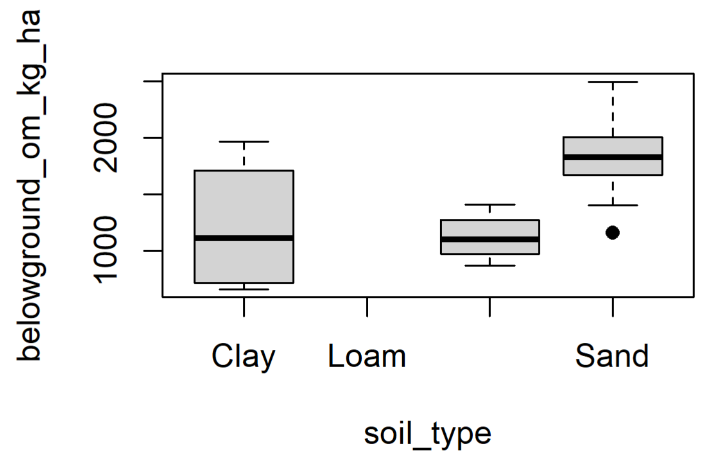
```
# Literature check
```



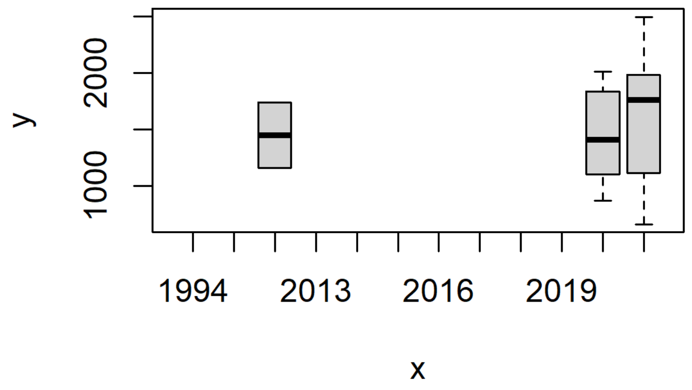

```
# Distribution and clean up outliers
```



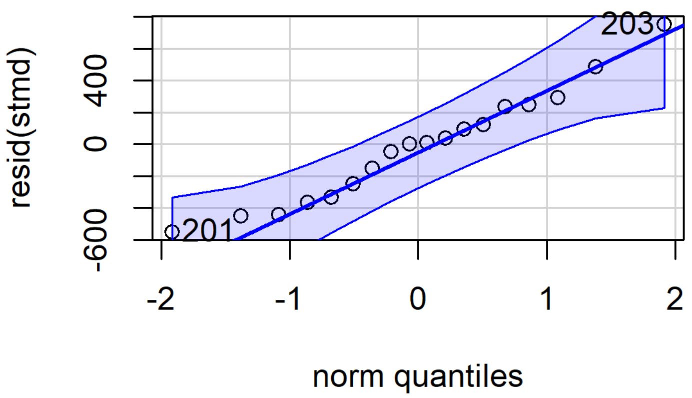
Soil type



Visual check




```
# Linear model analysis
stmd<-lm(belowground_om_kg_ha ~ year + soil_type , weights=weights_below, data=spring_barley)
print(anova(stmd))
Analysis of Variance Table

Response: belowground_om_kg_ha
          Df  Sum Sq Mean Sq F value  Pr(>F)
year       2  159276   79638  0.3939 0.68218
soil_type  2 2094846 1047423  5.1812 0.02215 *
Residuals 13 2628082  202160
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   1317 113 13     1072     1562

Results are averaged over the levels of: year, soil_type
Confidence level used: 0.95
```

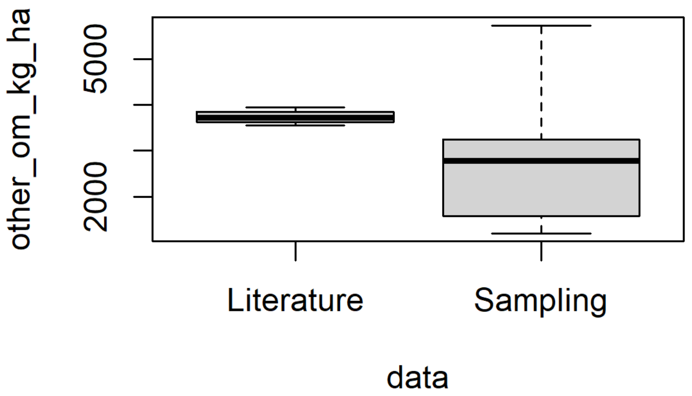


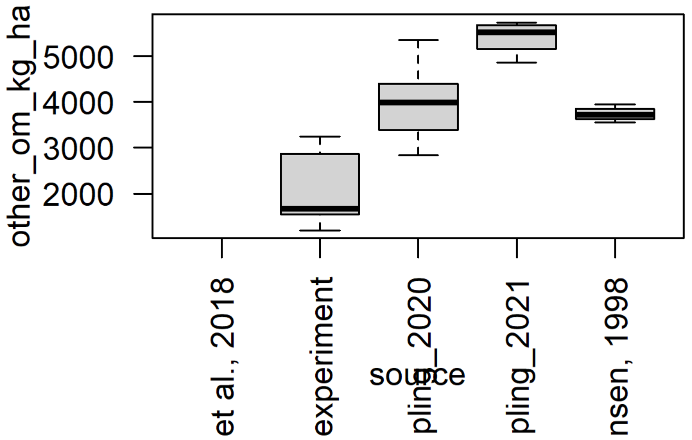

```
203 201
 16  14
   Shapiro-Wilk normality test
```

```
data:  resid(stmd)
W = 0.96945, p-value = 0.7872
```

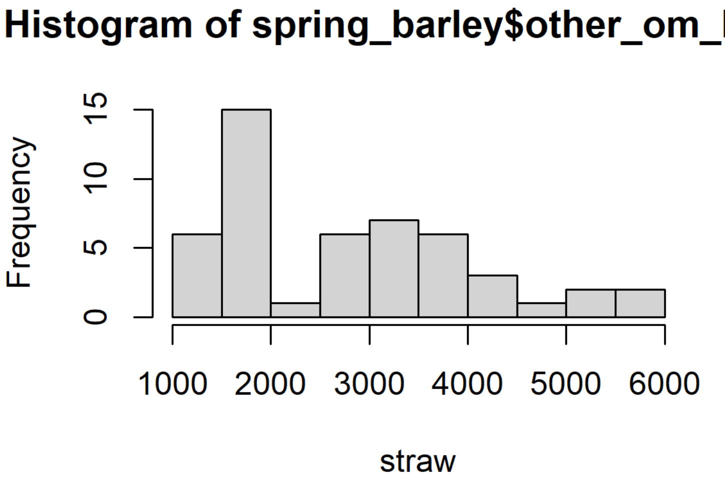
Straw

```
# Literature
```

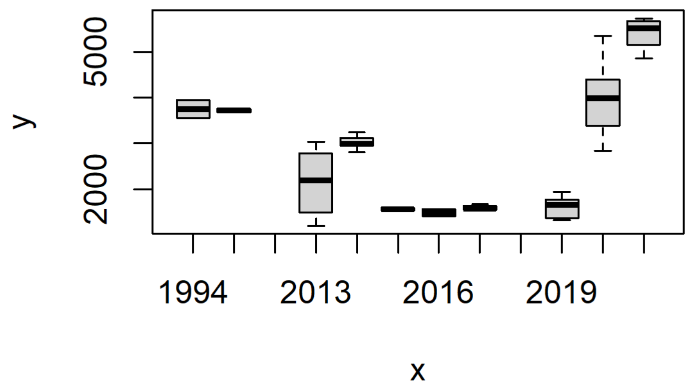




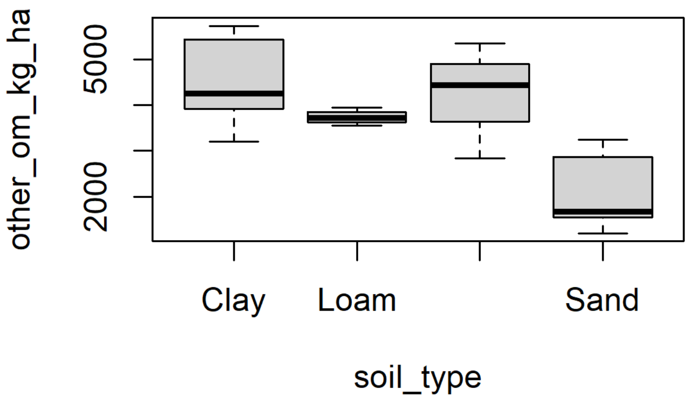

```
# Distribution and clean up outliers
```



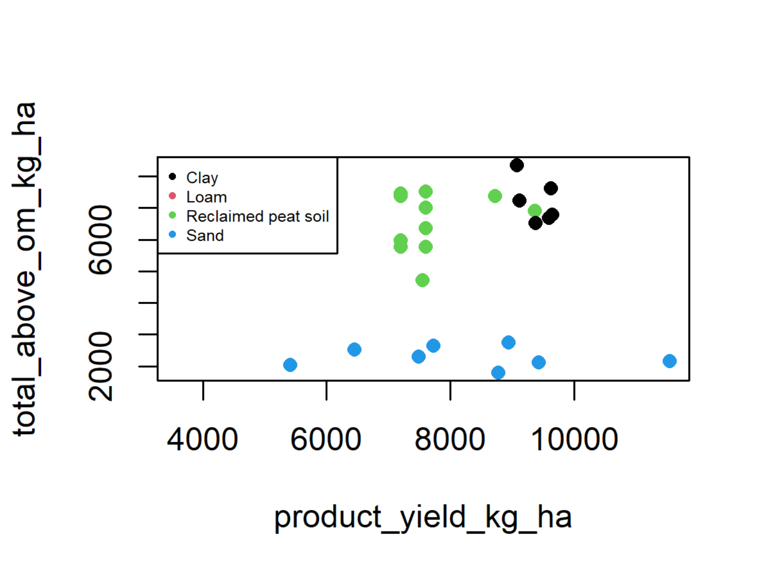
Visual check by year



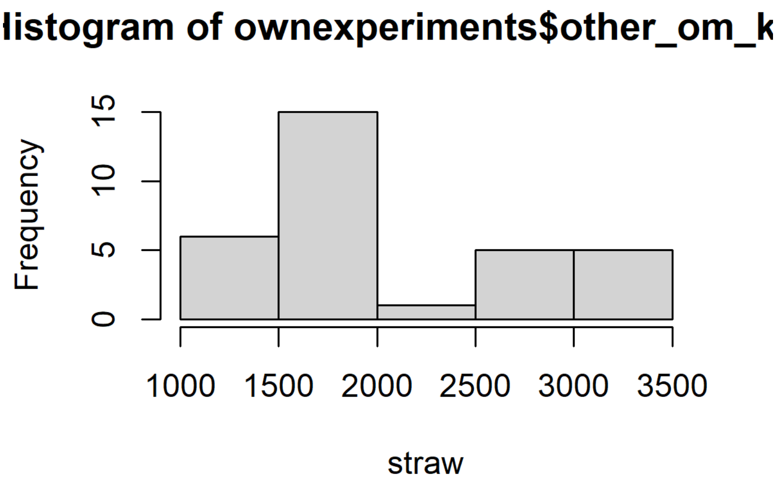
Soil type



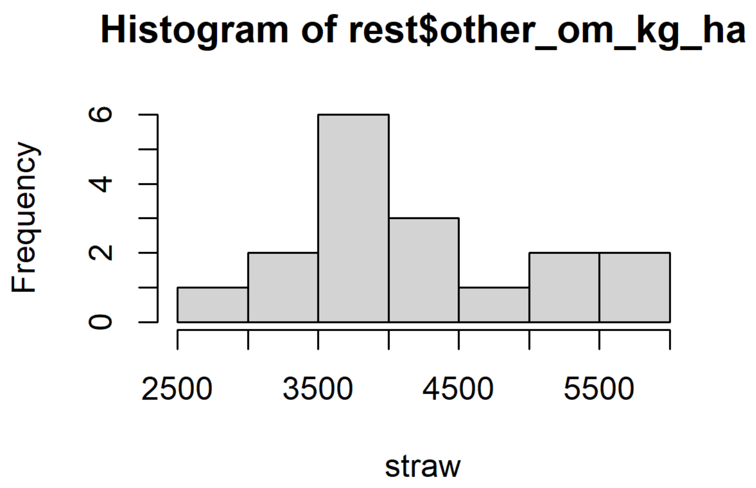
```
# Plot of yield vs aboveground biomass
```



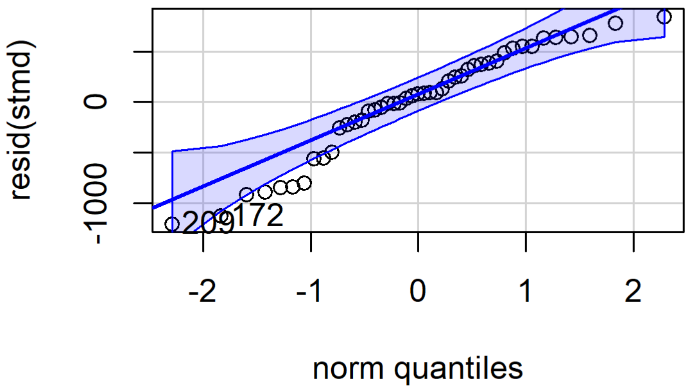

```
# Data from Vredepeel in previous own experiments is significanly lower than the rest and weighs in heavily.

ownexperiments <- spring_barley[spring_barley$source=="Own experiment",]
```




```
rest <- spring_barley[!spring_barley$source=="Own experiment",]
```



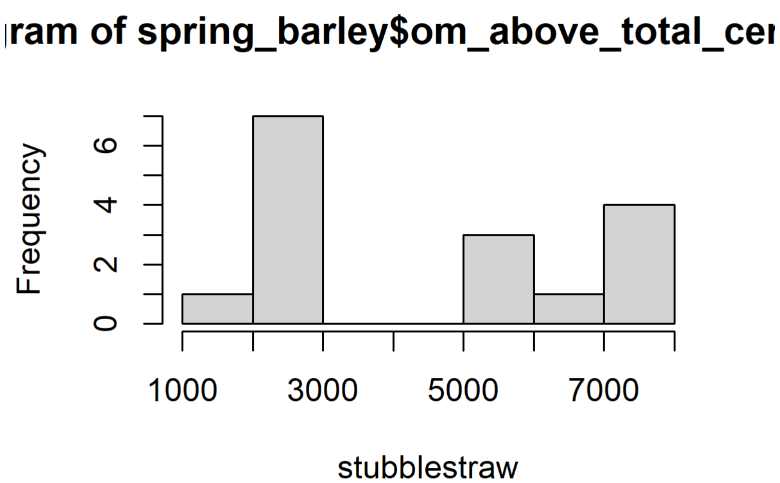

```
# Linear model analysis
stmd<-lm(other_om_kg_ha ~ soil_type + cultivar_variety , weights=weights_above, data=spring_barley)
print(anova(stmd))
Analysis of Variance Table

Response: other_om_kg_ha
                 Df   Sum Sq  Mean Sq F value    Pr(>F)
soil_type         2 51657611 25828806 78.7397 3.055e-14 ***
cultivar_variety  4 13105263  3276316  9.9879 1.265e-05 ***
Residuals        38 12465050   328028
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   3430 146 38     3135     3724

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
EMM_straw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   3430 146 38     3135     3724

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```



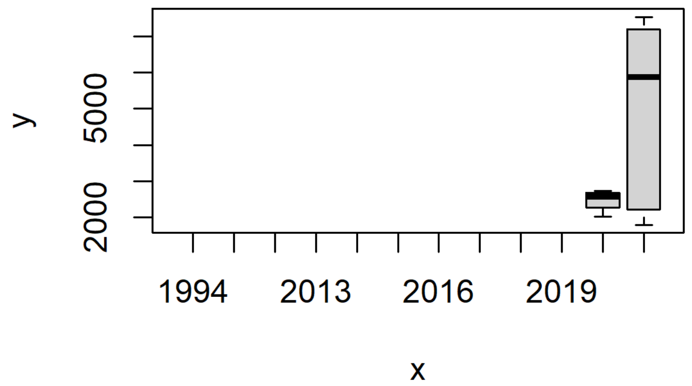

```
209 172
 19   3

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.12109, p-value = 0.4869
alternative hypothesis: two-sided
```

Stubble + Straw

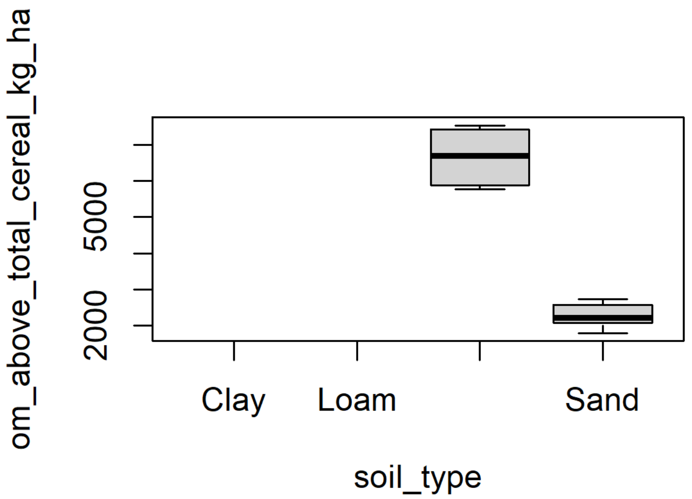
```
# Distribution and clean up outliers
```



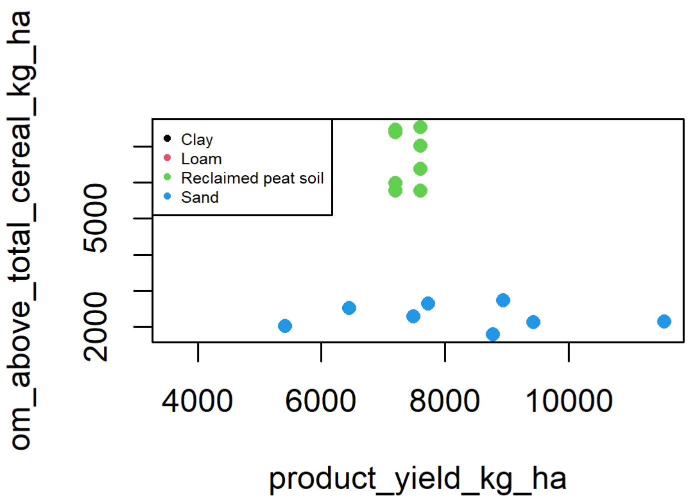

```
# Visual check
```



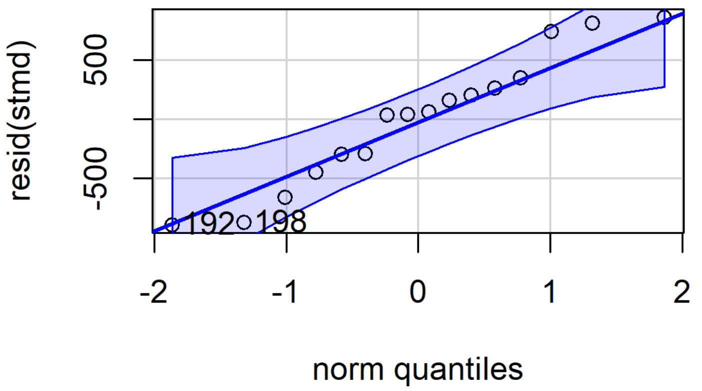
Soil type



Plot of yield vs aboveground biomass



```
# Linear model analysis
stmd<-lm(om_above_total_cereal_kg_ha ~ year + soil_type + cultivar_variety, weights=weights_above, data=spring_barley)
print(anova(stmd))
Analysis of Variance Table

Response: om_above_total_cereal_kg_ha
                 Df   Sum Sq  Mean Sq  F value    Pr(>F)
year              1 21167200 21167200  55.5071 7.732e-06 ***
soil_type         1 55678164 55678164 146.0057 4.477e-08 ***
cultivar_variety  1     1370     1370   0.0036    0.9532
Residuals        12  4576109   381342
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   4575 218 12     4099     5051

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubblestraw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   4575 218 12     4099     5051

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```




```
192 198
  9  15
    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.94997, p-value = 0.4892
```

Summary

```
# Stubble
sum(!is.na(spring_barley$aboveground_om_kg_ha))
 18
## IQR
summary(spring_barley$aboveground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   1322    1737    2521    2492    2867    4227      60 
```

```
# Roots
sum(!is.na(spring_barley$belowground_om_kg_ha))
 18
## IQR
summary(spring_barley$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
    664    1139    1566    1520    1863    2491      60 
# Straw
sum(!is.na(rest$other_om_kg_ha))
 17
## IQR
summary(rest$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   2836    3681    3991    4248    4854    5725      23 
# Stubble + straw
sum(!is.na(spring_barley$om_above_total_cereal_kg_ha))
 16
## IQR
summary(spring_barley$om_above_total_cereal_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   1795    2255    4251    4471    6530    7525      62 
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(EMM_stubble + EMM_straw, EMM_stubblestraw)
weight <- c(min(sum(!is.na(spring_barley$aboveground_om_kg_ha)), sum(!is.na(spring_barley$other_om_kg_ha))), sum(!is.na(spr
ing_barley$om_above_total_cereal_kg_ha)))

weighted.mean(values, weight, na.rm=TRUE)
 4972.02
```

Statistical testing

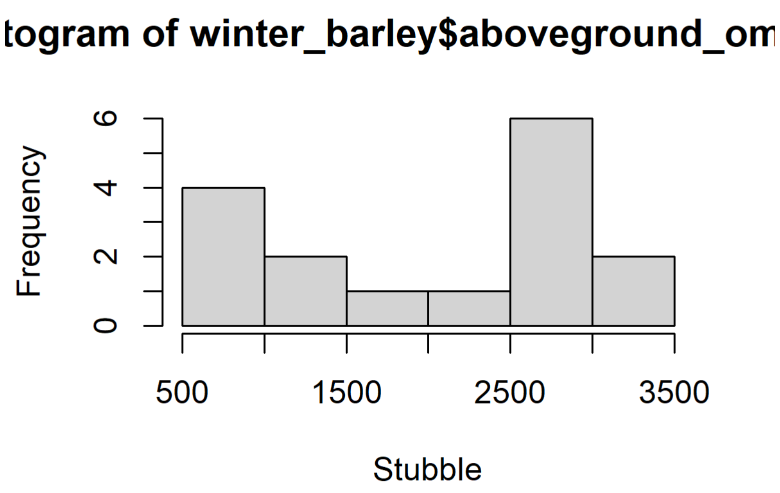
```
	Shapiro-Wilk normality test

data:  spring_barley$aboveground_om_kg_ha
W = 0.92511, p-value = 0.1592

	One Sample t-test

data:  spring_barley$aboveground_om_kg_ha * 0.3
t = 2.883, df = 17, p-value = 0.01033
alternative hypothesis: true mean is not equal to 570
95 percent confidence interval:
 617.6292 877.5725
sample estimates:
mean of x 
 747.6009 

	Shapiro-Wilk normality test

data:  spring_barley$belowground_om_kg_ha
W = 0.96478, p-value = 0.6958

	One Sample t-test

data:  spring_barley$belowground_om_kg_ha * 0.35
t = 4.4244, df = 17, p-value = 0.0003712
alternative hypothesis: true mean is not equal to 350
95 percent confidence interval:
 445.1746 618.6814
sample estimates:
mean of x 
  531.928 
```

```
    Shapiro-Wilk normality test

data:  log(spring_barley$other_om_kg_ha)
W = 0.92114, p-value = 0.002906

    Wilcoxon signed rank exact test

data:  spring_barley$other_om_kg_ha * 0.3
V = 961, p-value = 0.0003546
alternative hypothesis: true location is not equal to 630

    Shapiro-Wilk normality test

data:  spring_barley$om_above_total_cereal_kg_ha
W = 0.81301, p-value = 0.004075

    Shapiro-Wilk normality test

data:  log(spring_barley$om_above_total_cereal_kg_ha)
W = 0.82008, p-value = 0.005097

    Shapiro-Wilk normality test

data:  sqrt(spring_barley$om_above_total_cereal_kg_ha)
W = 0.81574, p-value = 0.004441

    Wilcoxon signed rank exact test

data:  spring_barley$other_om_kg_ha * 0.3
V = 137, p-value = 3.184e-07
alternative hypothesis: true location is not equal to 1200
```

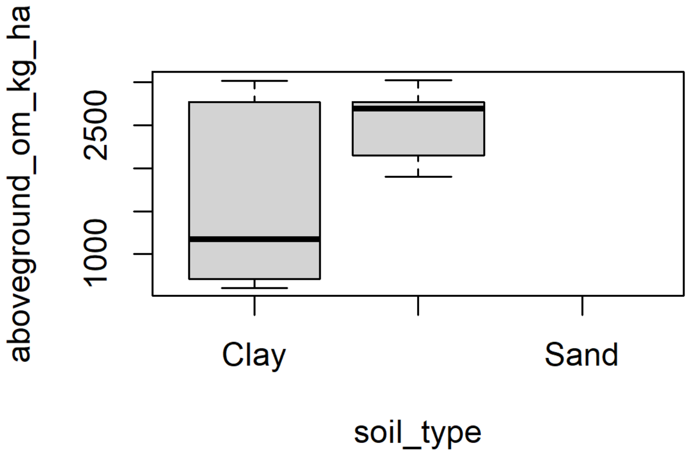
6.6 Winter barley

Stubble

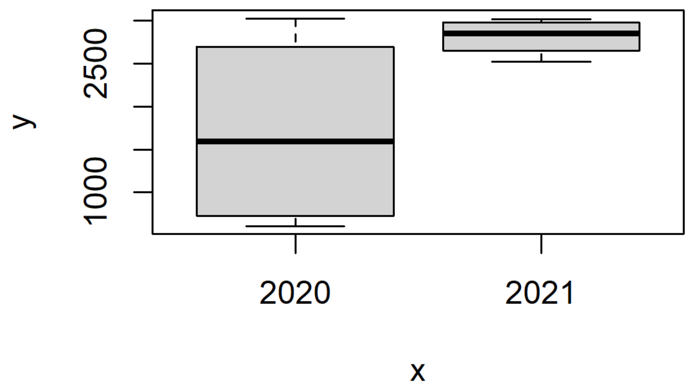
```
# Distribution and clean up outliers
```




```
# Soil type
```

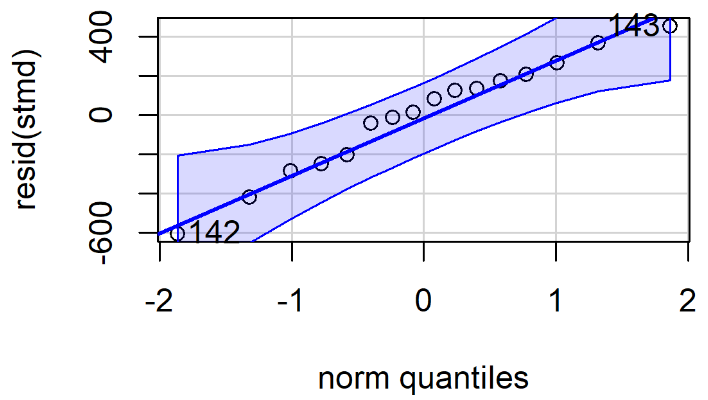



```
# Visual check
```




```
# Linear model analysis
stmd<-lm(aboveground_om_kg_ha ~ year + soil_type + cultivar_variety , weights=weights_above, data=winter_barley)
print(anova(stmd))
Analysis of Variance Table

Response: aboveground_om_kg_ha
                 Df  Sum Sq Mean Sq F value    Pr(>F)
year              1 3777124 3777124 33.2141 0.0001259 ***
soil_type         1 8625822 8625822 75.8511 2.887e-06 ***
cultivar_variety  2  152117   76058  0.6688 0.5319657
Residuals        11 1250926  113721
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   2727 119 11     2464     2989

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubble <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
```

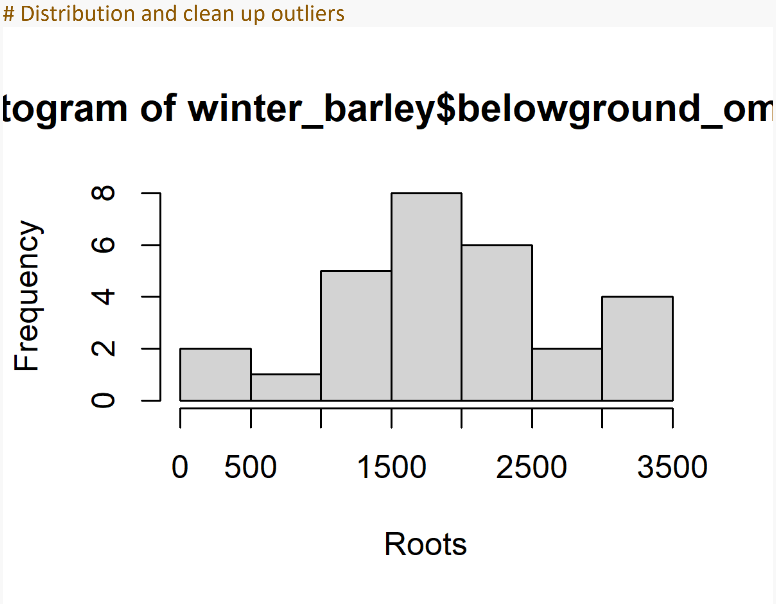
```
1      emmean  SE df lower.CL upper.CL
overall   2727 119 11     2464     2989

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



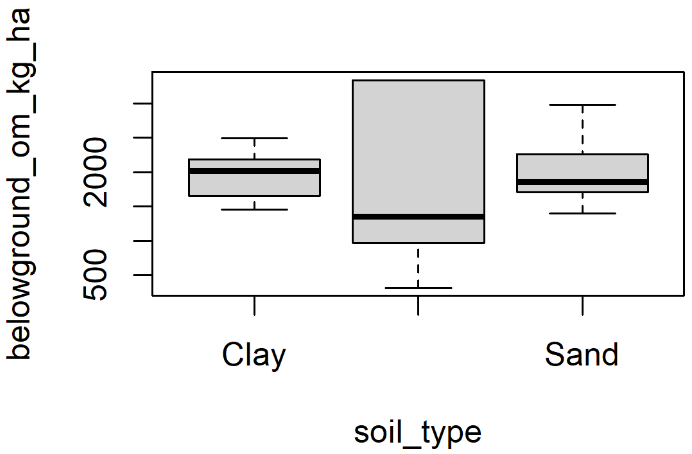

```
142 143
  8   9
   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.9707, p-value = 0.8498
```

Belowground

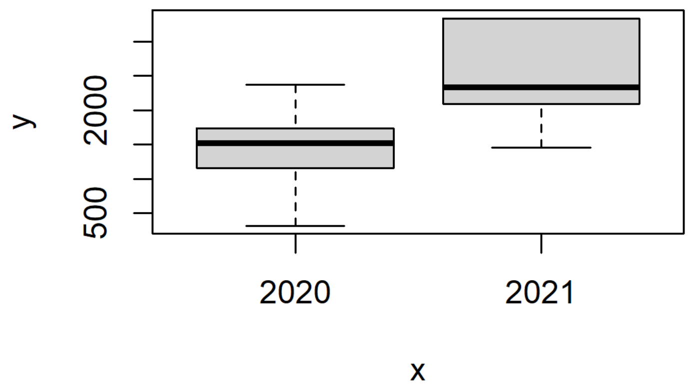
```
# Distribution and clean up outliers
```



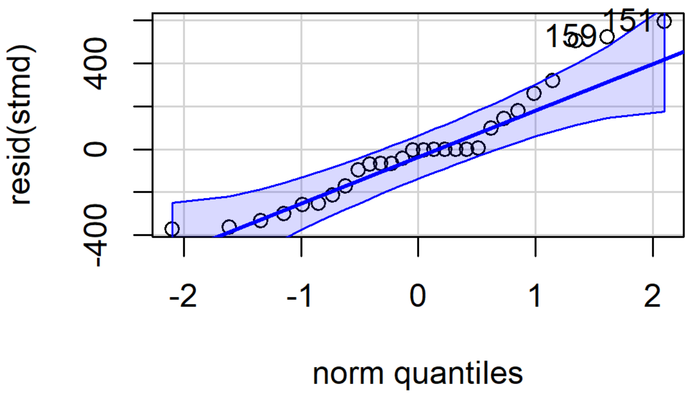

```
# Soil type
```




```
# Visual check
```



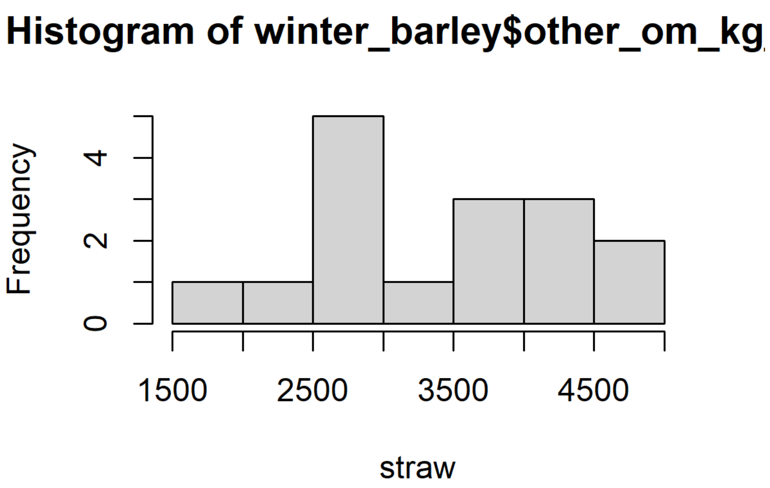

```
# Linear model analysis
stmd<-lm(belowground_om_kg_ha ~ year + soil_type + cultivar_variety  + soil_type:location, weights=weights_below, data=winter_
barley)
print(anova(stmd))
Analysis of Variance Table

Response: belowground_om_kg_ha
                   Df  Sum Sq Mean Sq F value    Pr(>F)
year                1 8177996 8177996 94.6911 3.117e-09 ***
soil_type           2 3148208 1574104 18.2262 2.574e-05 ***
cultivar_variety    2 4323841 2161920 25.0324 2.760e-06 ***
soil_type:location  1  384481  384481  4.4518   0.04704 *
Residuals          21 1813664   86365
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean   SE df lower.CL upper.CL
 overall   1783 87.2 21     1601     1964

Results are averaged over the levels of: year, cultivar_variety, location, soil_type
Confidence level used: 0.95
```



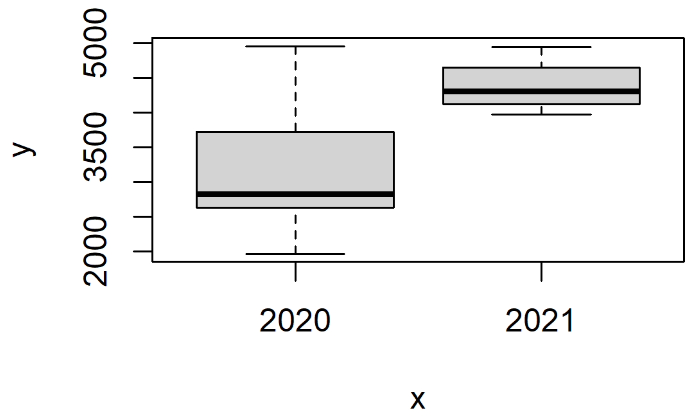

```
151 159 
 11  19 

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.20506, p-value = 0.1897
alternative hypothesis: two-sided
```

Straw

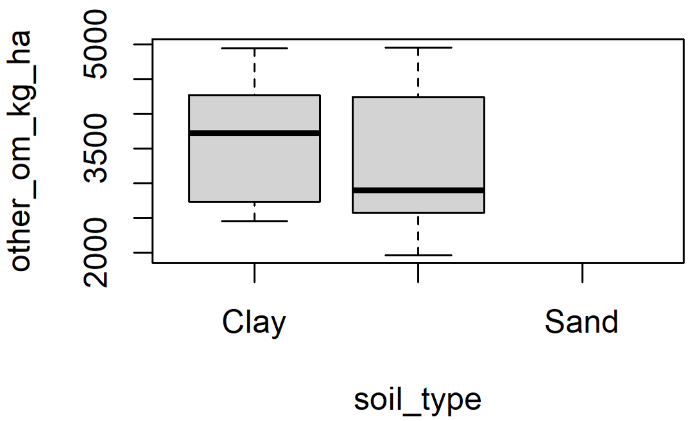
```
# Distribution and clean up outliers
```



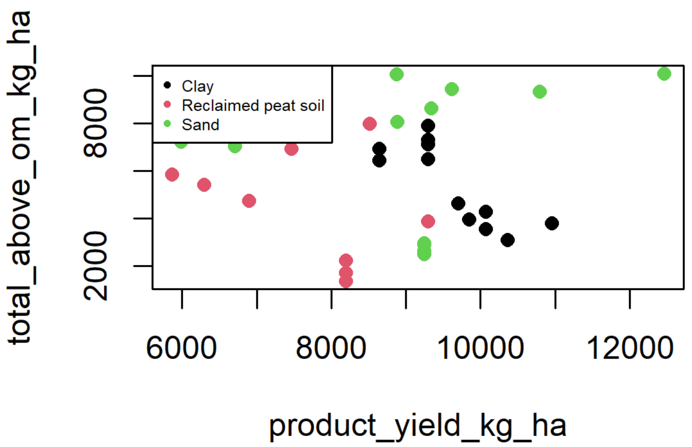

```
# Visual check
```



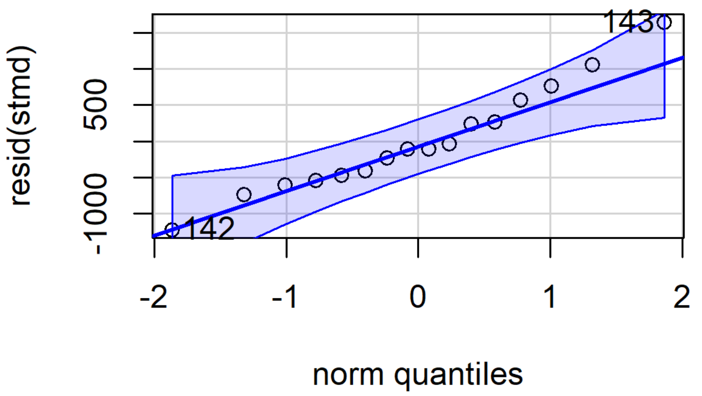
Soil type



Plot of yield vs aboveground biomass



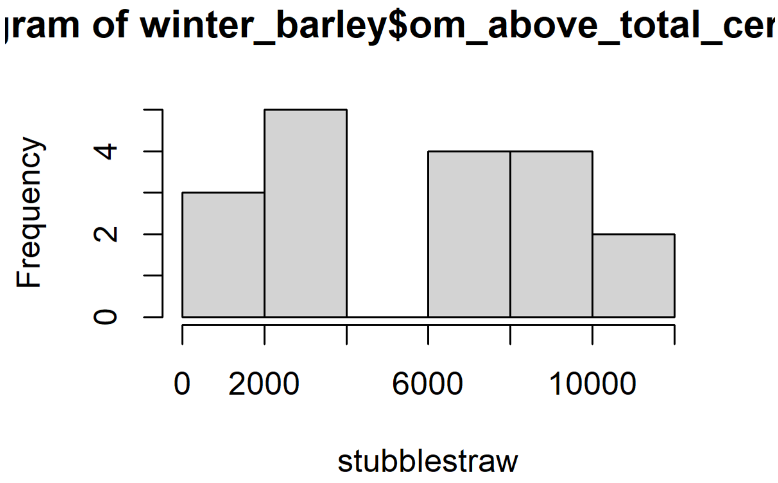
```
# Linear model analysis
stmd<-lm(other_om_kg_ha ~ year + soil_type + cultivar_variety, weights=weights_above, data=winter_barley)
print(anova(stmd))
Analysis of Variance Table

Response: other_om_kg_ha
                 Df  Sum Sq Mean Sq F value  Pr(>F)
year              1 4588043 4588043  6.3056 0.02893 *
soil_type         1  137708  137708  0.1893 0.67195
cultivar_variety  2  400138  200069  0.2750 0.76467
Residuals        11 8003814  727619
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   3908 302 11     3244     4572

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_straw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   3908 302 11     3244     4572

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



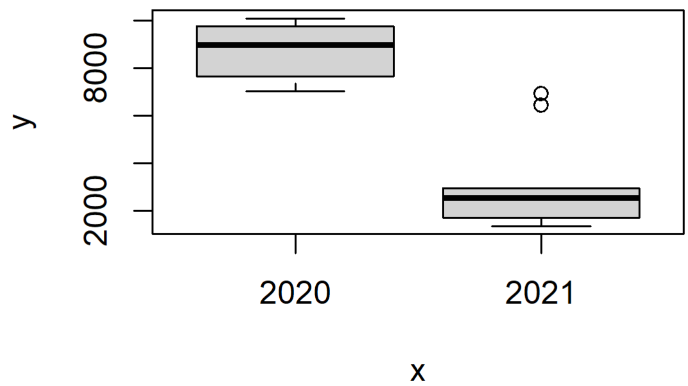

```
143 142
  9   8
    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.96643, p-value = 0.7779
```

Stubble + Straw

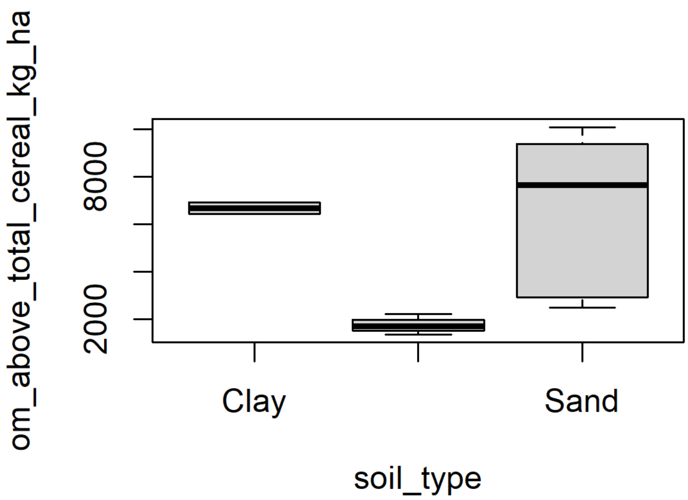
```
# Distribution and clean up outliers
```



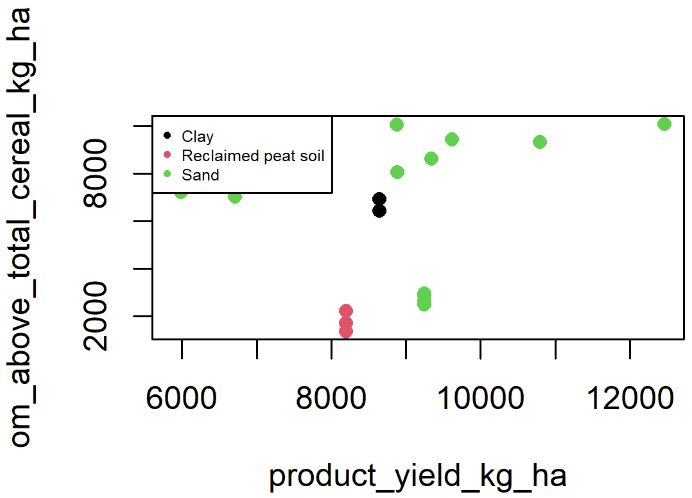
Visual check



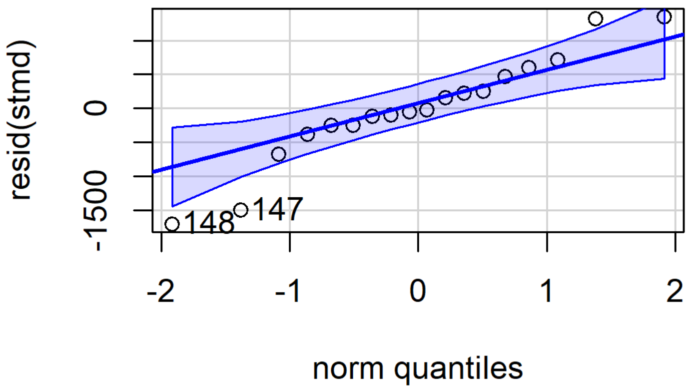
Soil type



Plot of yield vs aboveground biomass




```
# Linear model analysis
stmd<-lm(om_above_total_cereal_kg_ha ~ year + soil_type + cultivar_variety, weights=weights_above, data=winter_barley)
print(anova(stmd))
Analysis of Variance Table

Response: om_above_total_cereal_kg_ha
          Df    Sum Sq   Mean Sq F value    Pr(>F)
year       1 138865893 138865893 182.377 2.025e-09 ***
soil_type  2  33373071  16686536  21.915 4.873e-05 ***
Residuals 14  10659930    761424
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print(emmeans(stmd, specs = ~ 1, type="response"))
 1       emmean  SE df lower.CL upper.CL
 overall   6223 327 14     5521     6925

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
EMM_stubblestraw <- as.numeric(paste(as.data.frame(print(emmeans(stmd, specs = ~ 1, type="response")))[,2]))
 1       emmean  SE df lower.CL upper.CL
 overall   6223 327 14     5521     6925

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```




```
148 147
  2   1
    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.94433, p-value = 0.343
```

Summary

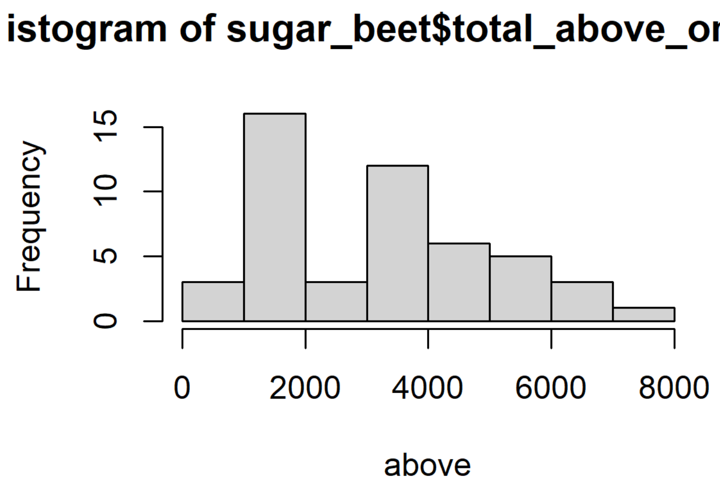
```
# Stubble
sum(!is.na(winter_barley$aboveground_om_kg_ha))
 16
## IQR
summary(winter_barley$aboveground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  609.9   981.2  2335.2  1967.9  2766.1  3018.5      18
# Roots
sum(!is.na(winter_barley$belowground_om_kg_ha))
 28
## IQR
summary(winter_barley$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  320.1  1477.5  1843.5  1956.9  2399.4  3331.9       6
# Straw
sum(!is.na(winter_barley$other_om_kg_ha))
 16
## IQR
summary(winter_barley$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   1968    2704    3311    3458    4252    4953      18
# Stubble + straw
sum(!is.na(winter_barley$om_above_total_cereal_kg_ha))
 18
## IQR
summary(winter_barley$om_above_total_cereal_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
   1372    2519    6679    5618    8480   10065      16
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(EMM_stubble + EMM_straw, EMM_stubblestraw)
weight <- c(min(sum(!is.na(spring_wheat$aboveground_om_kg_ha)), sum(!is.na(spring_wheat$other_om_kg_ha))), sum(!is.na(spring_wheat$om_above_total_cereal_kg_ha)))

weighted.mean(values, weight, na.rm=TRUE)
 6516.927
```

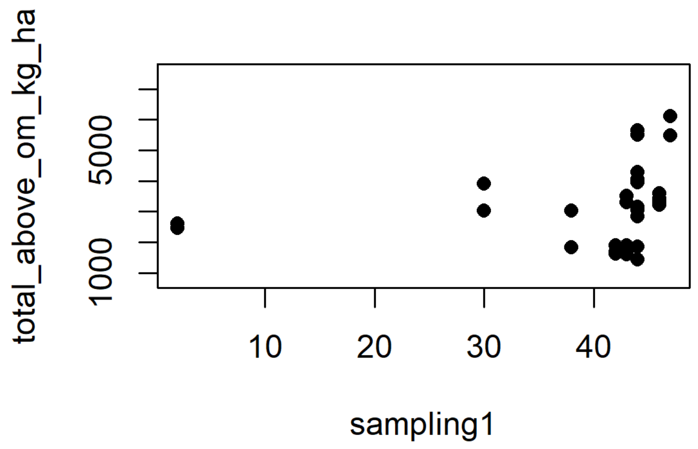
Statistical testing

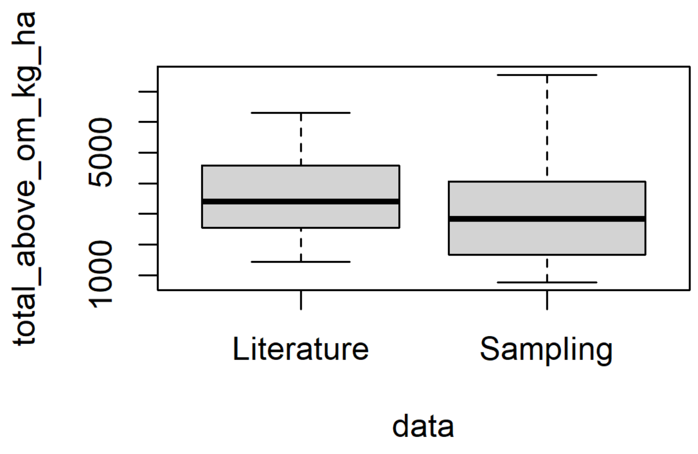
```
   Shapiro-Wilk normality test

data:  log(winter_barley$aboveground_om_kg_ha)
W = 0.80589, p-value = 0.003264

   Wilcoxon signed rank exact test

data:  winter_barley$aboveground_om_kg_ha * 0.3
V = 56, p-value = 0.5619
alternative hypothesis: true location is not equal to 630

   Shapiro-Wilk normality test

data:  winter_barley$belowground_om_kg_ha
W = 0.95588, p-value = 0.2773

   One Sample t-test

data:  winter_barley$belowground_om_kg_ha * 0.35
t = 3.6247, df = 27, p-value = 0.001184
alternative hypothesis: true mean is not equal to 490
95 percent confidence interval:
 574.5864 795.2728
sample estimates:
mean of x
 684.9296

   Shapiro-Wilk normality test

data:  winter_barley$other_om_kg_ha
W = 0.93293, p-value = 0.2712

   One Sample t-test

data:  winter_barley$other_om_kg_ha * 0.3
t = 3.6693, df = 15, p-value = 0.002278
alternative hypothesis: true mean is not equal to 780
95 percent confidence interval:
  887.9066 1187.0284
sample estimates:
mean of x
 1037.468

   Shapiro-Wilk normality test

data:  winter_barley$om_above_total_cereal_kg_ha
W = 0.86331, p-value = 0.01383

   One Sample t-test

data:  winter_barley$other_om_kg_ha * 0.3
t = -5.3091, df = 15, p-value = 8.752e-05
alternative hypothesis: true mean is not equal to 1410
95 percent confidence interval:
  887.9066 1187.0284
sample estimates:
mean of x
 1037.468
```

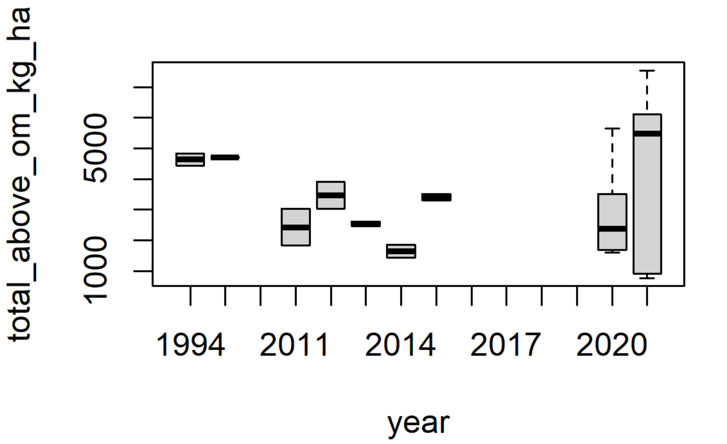
6.7 Sugar beet

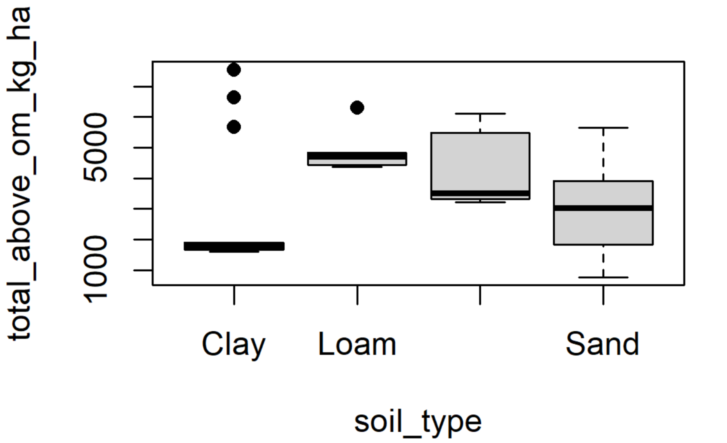
Aboveground



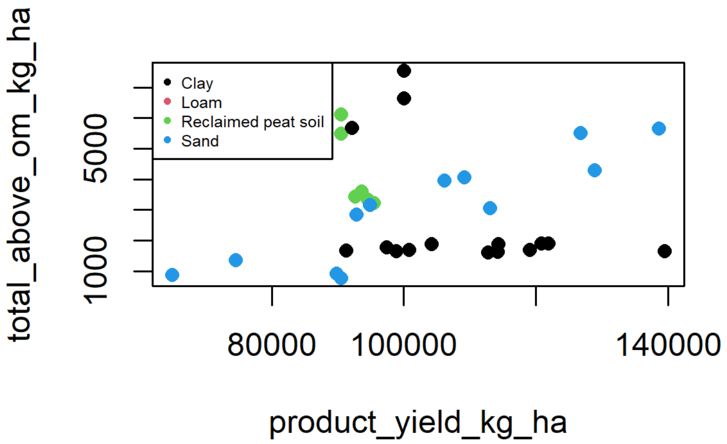




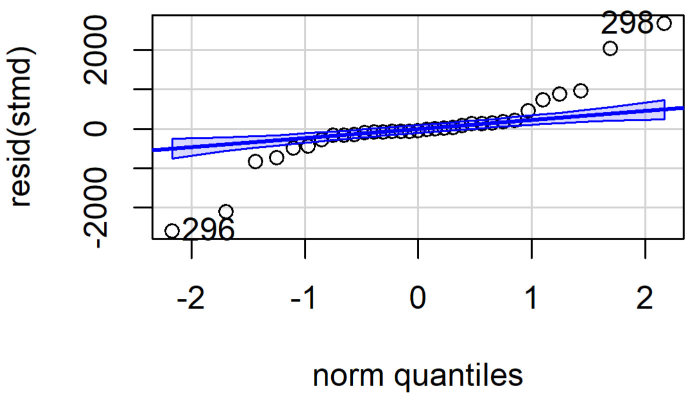




Mean of literature data: 658.3655
Mean of samples: 619.7925

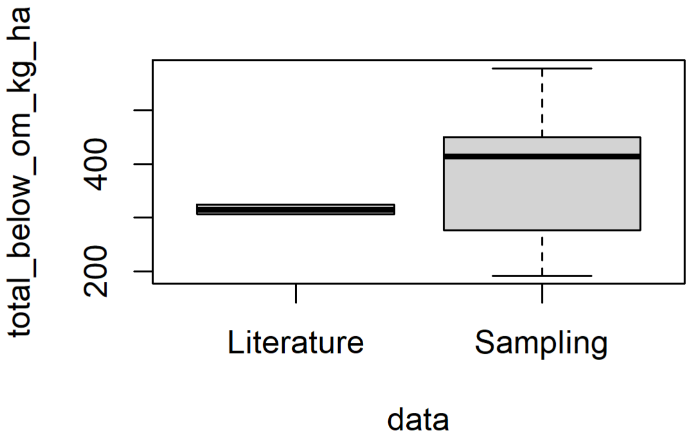


```
Call:
lm(formula = total_above_om_kg_ha ~ product_yield_kg_ha, data = sugar_beet,
    weights = weights_above)

Residuals:
    Min      1Q  Median      3Q     Max
-2154.5 -1430.6  -184.6   854.0  4473.9

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.712e+03  2.069e+03   0.828    0.414
product_yield_kg_ha 1.340e-02  1.974e-02   0.679    0.502

Residual standard error: 1869 on 31 degrees of freedom
  (18 observations deleted due to missingness)
Multiple R-squared:  0.01465,	Adjusted R-squared:  -0.01714
F-statistic: 0.4609 on 1 and 31 DF,  p-value: 0.5022
Analysis of Variance Table

Response: total_above_om_kg_ha
                Df   Sum Sq  Mean Sq F value    Pr(>F)
year             1  8412548  8412548  7.5391   0.01126 *
cultivar_variety  7 74707453 10672493  9.5644 1.195e-05 ***
Residuals       24 26780511  1115855
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   3586 233 24     3104     4067

Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```

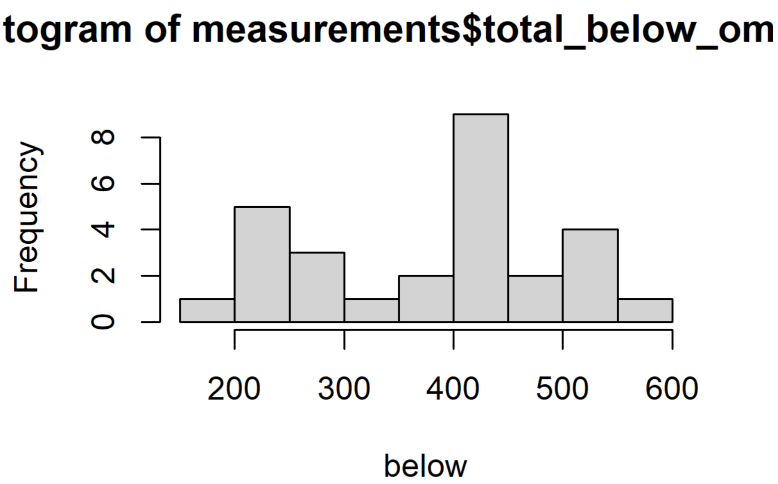



```
298 296
 27  25

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.2286, p-value = 0.05353
alternative hypothesis: two-sided
```

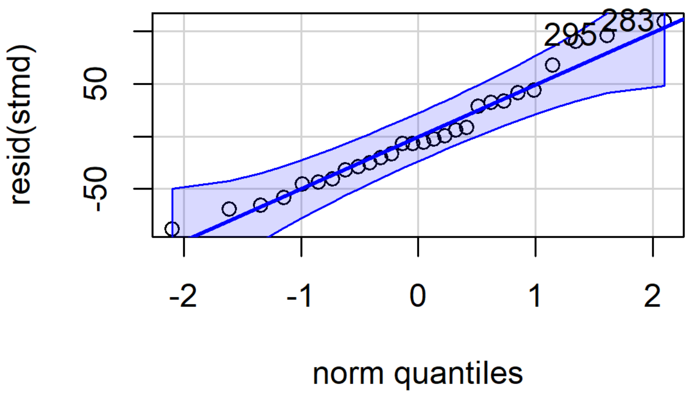
Belowground




```
Mean of literature data: 112.14
Mean of samples: 131.5063
```



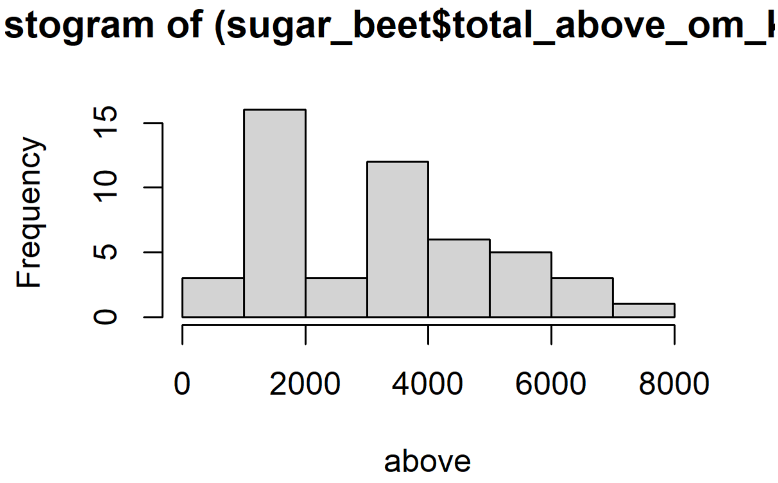

```
Mean of literature data: 64.08
Mean of samples: 75.14648
Analysis of Variance Table

Response: total_below_om_kg_ha
             Df Sum Sq Mean Sq F value    Pr(>F)
year            1  58307   58307 16.7491 0.0005666 ***
soil_type       2 216083  108042 31.0356 7.386e-07 ***
cultivar_variety  4  11430    2858  0.8209 0.5270862
Residuals      20  69624    3481
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall    415 16.1 20      382      449

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



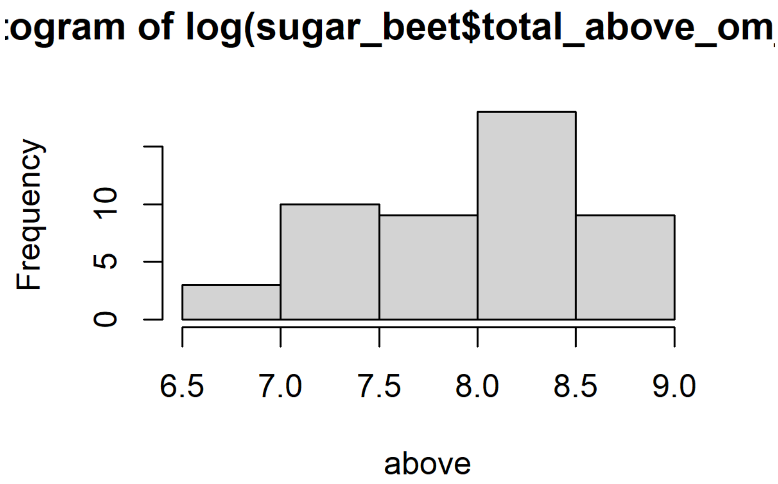

```
283 295
 10  22

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.11325, p-value = 0.8262
alternative hypothesis: two-sided
```

Summary and statistical testing

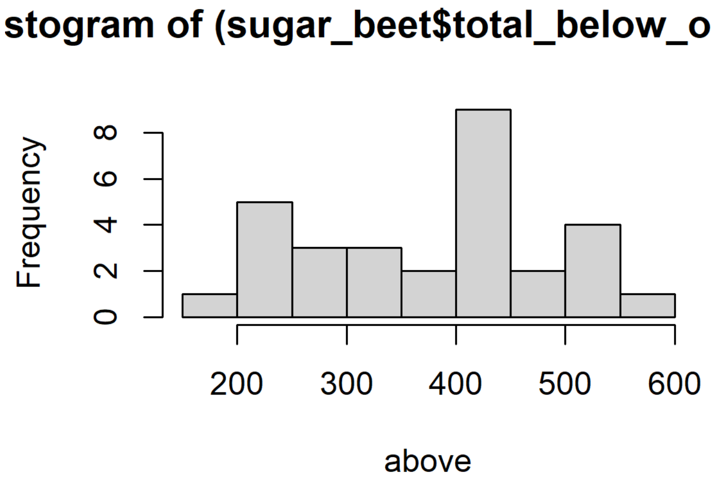
```
# Aboveground
sum(!is.na(sugar_beet$total_above_om_kg_ha))
 49
## IQR
summary(sugar_beet$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
    771    1771    3043    3245    4378    7527       2 
# Belowground
sum(!is.na(sugar_beet$total_below_om_kg_ha))
 30
## IQR
summary(sugar_beet$total_below_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
  192.4   295.0   404.1   371.7   438.4   577.0      21 
# Statistical testing

## Aboveground
```




```
    Shapiro-Wilk normality test

data:  log(sugar_beet$total_above_om_kg_ha)
W = 0.95964, p-value = 0.09151
```



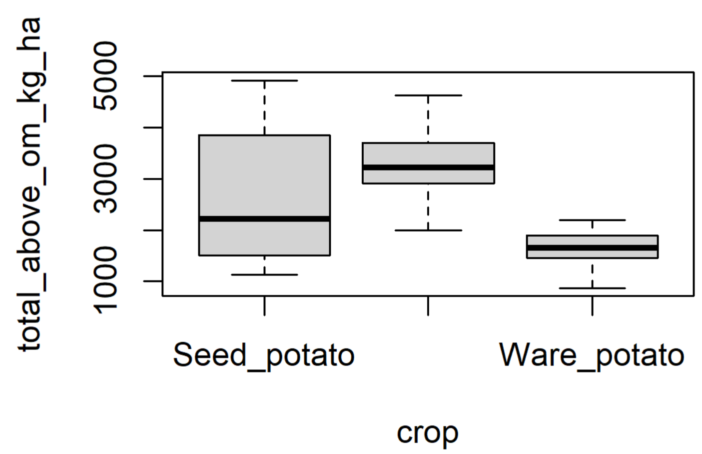

```
    One Sample t-test

data:  log(sugar_beet$total_above_om_kg_ha)
t = -8.3143, df = 48, p-value = 7.407e-11
alternative hypothesis: true mean is not equal to 8.612503
95 percent confidence interval:
 7.774579 8.100926
sample estimates:
mean of x 
 7.937752 
## Belowground

    Shapiro-Wilk normality test

data:  sugar_beet$total_below_om_kg_ha
W = 0.93998, p-value = 0.09087
```

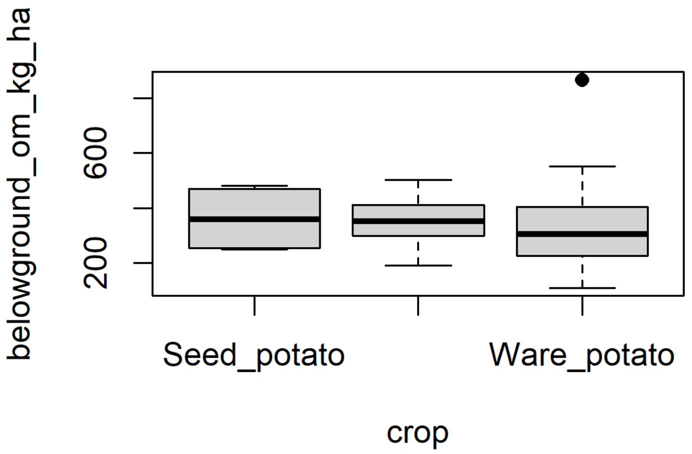


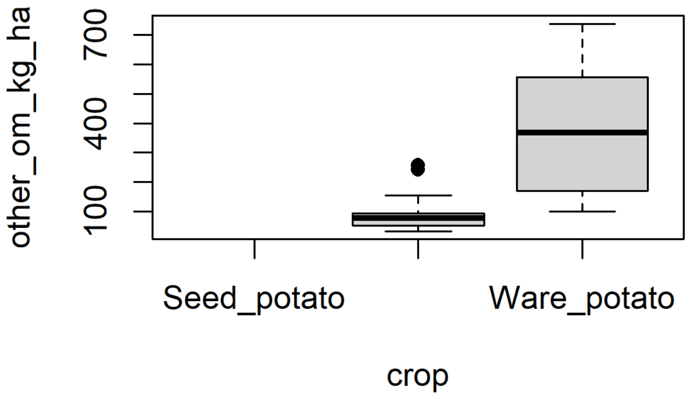

```
	One Sample t-test

data:  log(sugar_beet$total_below_om_kg_ha)
t = -5.7253, df = 29, p-value = 3.392e-06
alternative hypothesis: true mean is not equal to 6.214608
95 percent confidence interval:
 5.744896 5.992155
sample estimates:
mean of x 
 5.868525 
```

6.8 Potatoes - general results

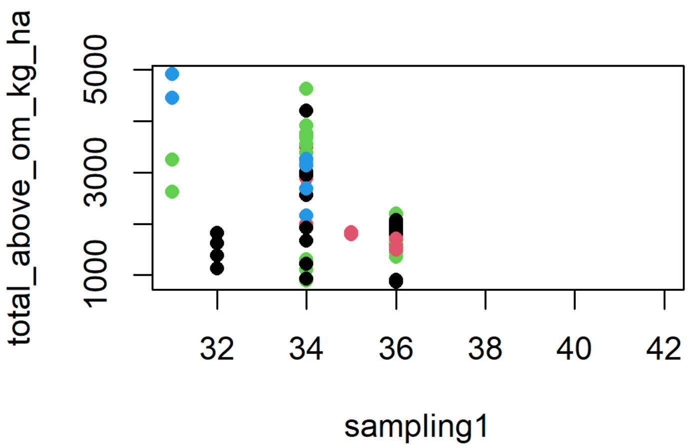
```
# Plots by potato crop type
```



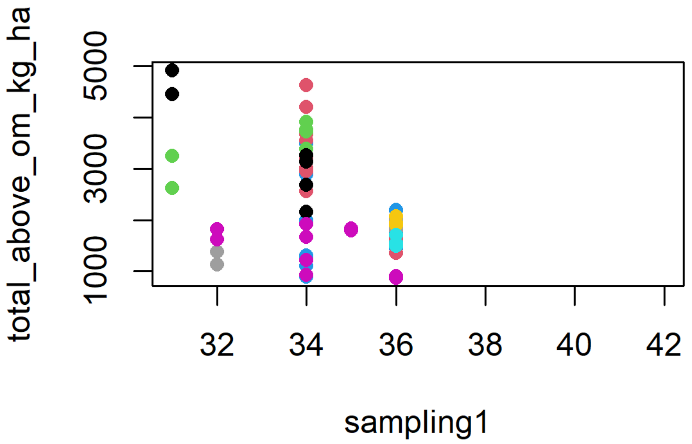




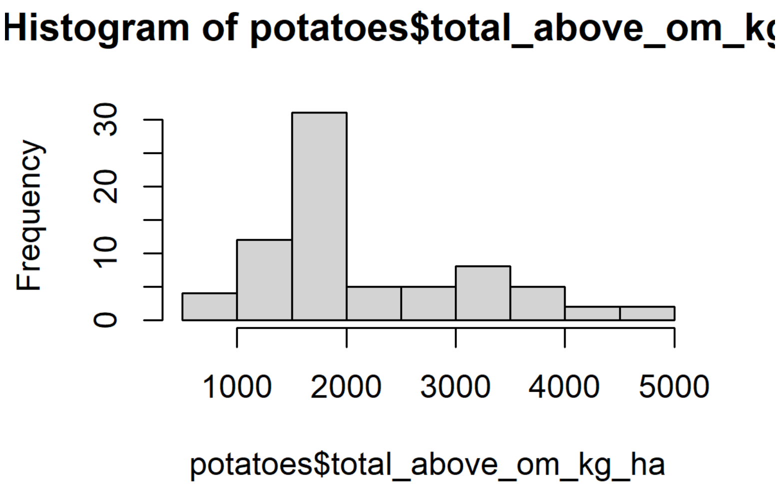

```
# Against sampling moment - colour leaf development class
```



```
# Against sampling moment - colour earliness class
```



Aboveground

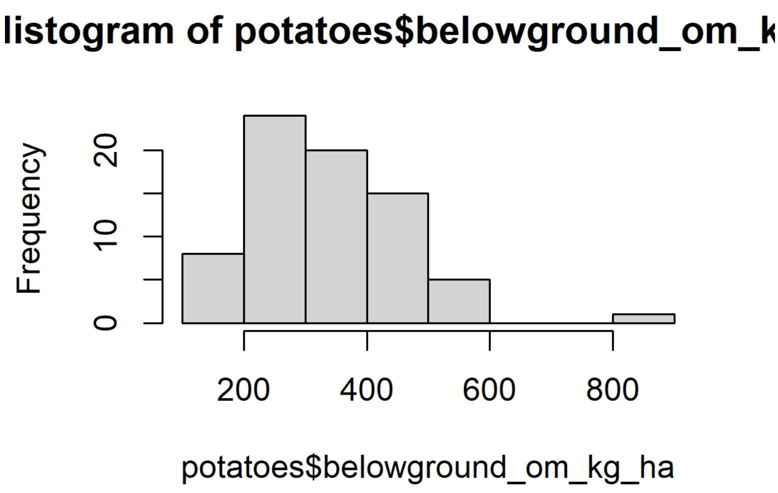



```
   One-sample Kolmogorov-Smirnov test

data:  log(potatoes$total_above_om_kg_ha)
D = 1, p-value = 1.332e-15
alternative hypothesis: two-sided

   Pairwise comparisons using Wilcoxon rank sum exact test

data:  potatoes$total_above_om_kg_ha and potatoes$crop

             Seed_potato Starch_potato
Starch_potato 0.17        -
Ware_potato   0.17        6.6e-15

P value adjustment method: BH
```

Seed potato doesn't differ from the other potato types while starch and ware potato have significantly different amount of aboveground biomass.

Belowground

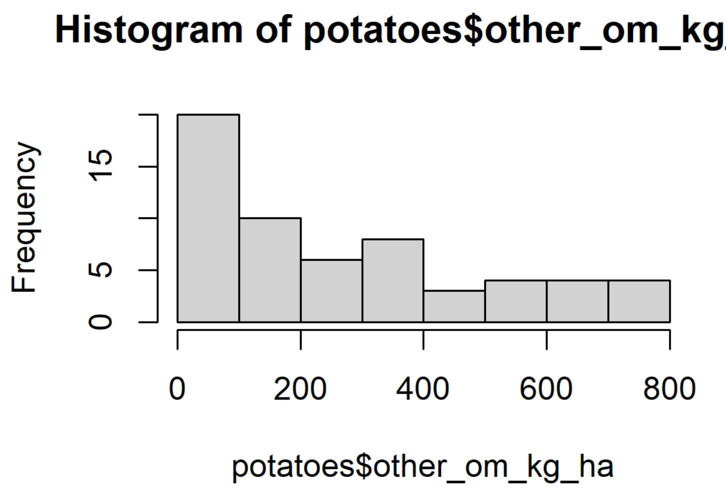
```
# Distribution
```




```
   Shapiro-Wilk normality test

data:  potatoes$belowground_om_kg_ha
W = 0.93868, p-value = 0.001491
pairwise.wilcox.test(potatoes$total_above_om_kg_ha, potatoes$crop,
            p.adjust.method = "BH")

   Pairwise comparisons using Wilcoxon rank sum exact test

data:  potatoes$total_above_om_kg_ha and potatoes$crop

             Seed_potato Starch_potato
Starch_potato 0.17        -
Ware_potato   0.17        6.6e-15

P value adjustment method: BH
```

Ware and starch potato are significantly different while seed potato is not significantly different from the other.

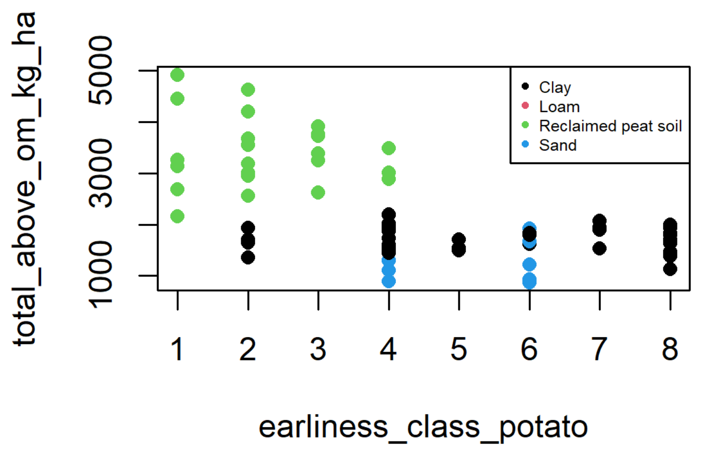
Baby potatoes




```
   Shapiro-Wilk normality test

data:  log(potatoes$other_om_kg_ha)
W = 0.94444, p-value = 0.009363
   Kruskal-Wallis rank sum test

data:  other_om_kg_ha by crop
Kruskal-Wallis chi-squared = 32.208, df = 1, p-value = 1.385e-08
```

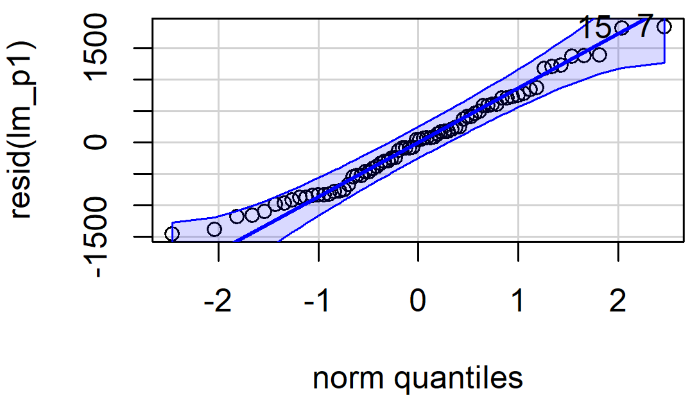
Data does not have a normal distribution

Plots of aboveground biomass against 1. earliness class and 2. leaf development class

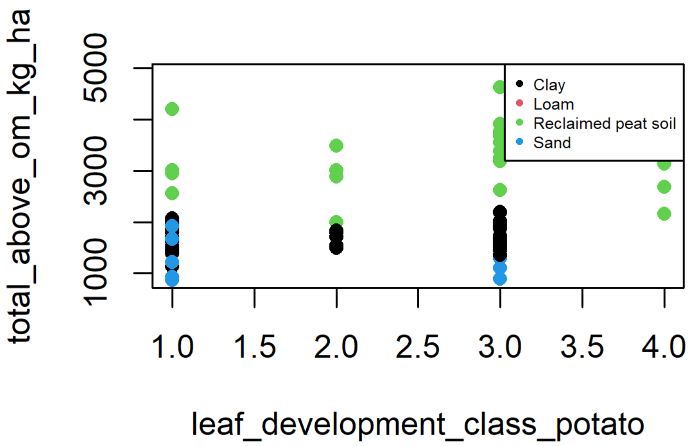



```
Call:
lm(formula = total_above_om_kg_ha ~ earliness_class_potato, data = potatoes,
   weights = weights_above)

Residuals:
    Min       1Q   Median       3Q      Max
-1460.23  -590.62    37.29   575.61  1828.81
```

```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)             3349.83     208.71  16.050  < 2e-16 ***
earliness_class_potato  -265.42      42.65  -6.223 3.15e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 783.1 on 70 degrees of freedom
  (6 observations deleted due to missingness)
Multiple R-squared:  0.3562,	Adjusted R-squared:  0.347 
F-statistic: 38.72 on 1 and 70 DF,  p-value: 3.152e-08
```

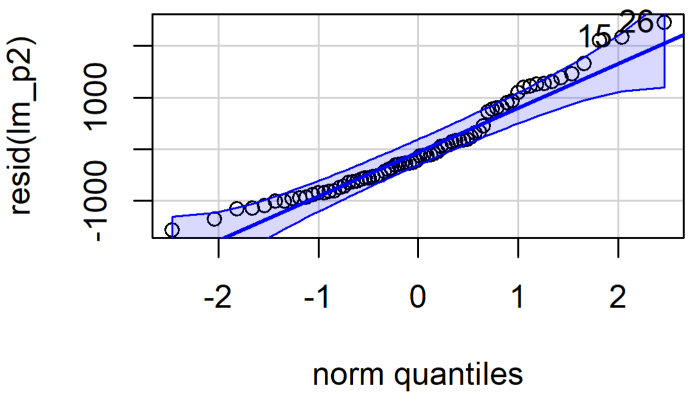



```
 7 15 
 6 13 

	One-sample Kolmogorov-Smirnov test

data:  resid(lm_p1)
D = 0.072115, p-value = 0.8219
alternative hypothesis: two-sided
```




```
Call:
```

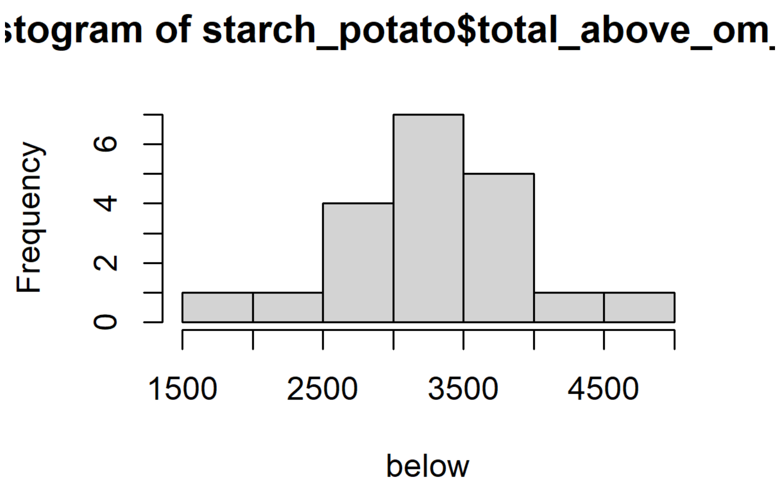
```
lm(formula = total_above_om_kg_ha ~ leaf_development_class_potato,
    data = potatoes, weights = weights_above)

Residuals:
    Min      1Q  Median      3Q     Max 
-1565.8  -635.0  -183.6   519.5  2449.1 

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)    
(Intercept)                     1407.0      253.5   5.550 4.77e-07 ***
leaf_development_class_potato    350.1      103.5   3.383  0.00118 ** 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 904.8 on 70 degrees of freedom
  (6 observations deleted due to missingness)
Multiple R-squared:  0.1405,	Adjusted R-squared:  0.1282 
F-statistic: 11.44 on 1 and 70 DF,  p-value: 0.001179
```

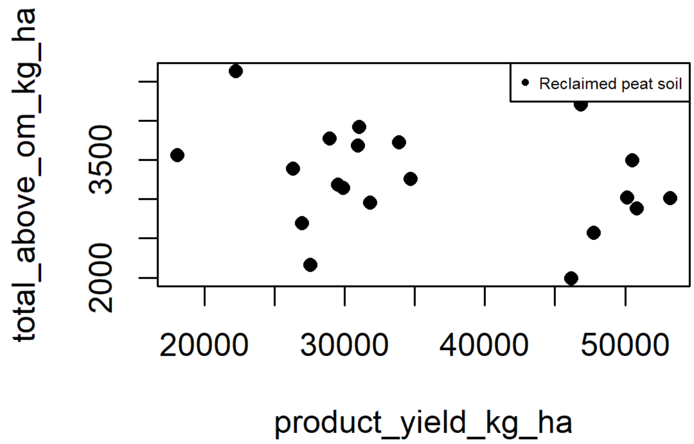



```
26 15 
24 13 

	One-sample Kolmogorov-Smirnov test

data:  resid(lm_p2)
D = 0.11162, p-value = 0.3078
alternative hypothesis: two-sided
```

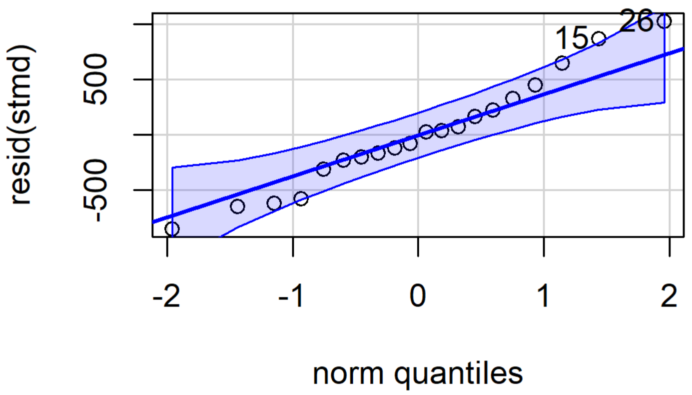
6.9 Starch potato

Aboveground



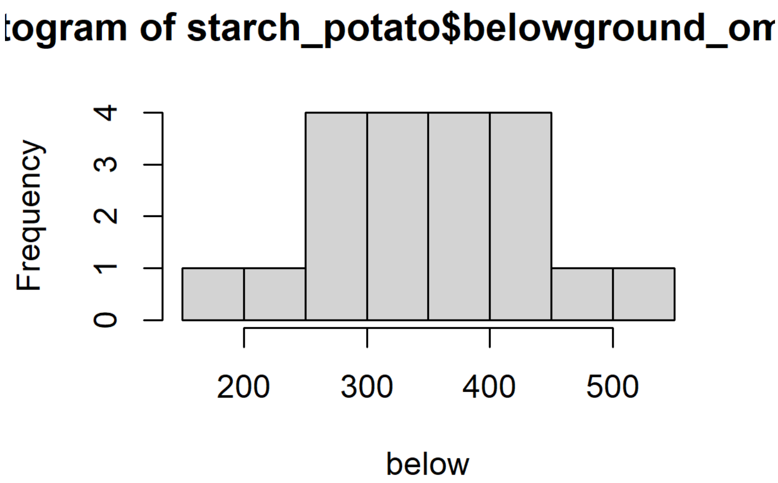



```
Analysis of Variance Table

Response: total_above_om_kg_ha
                Df  Sum Sq Mean Sq F value  Pr(>F)
cultivar_variety  4 3301561  825390   2.627 0.07626 .
Residuals        15 4712985  314199
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   3260 125 15     2993     3527

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```



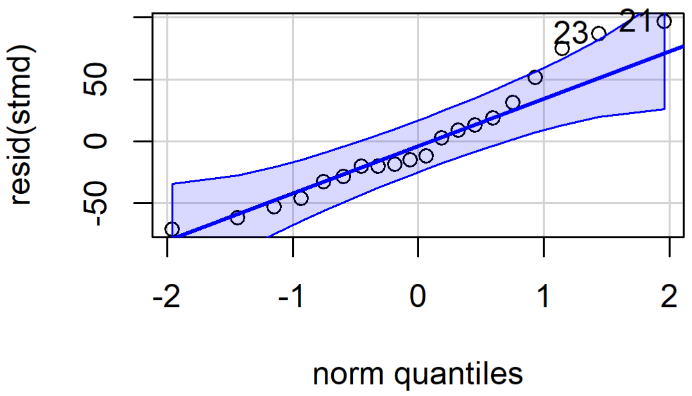

```
26 15
16  5

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.093533, p-value = 0.9878
alternative hypothesis: two-sided
```

Belowground



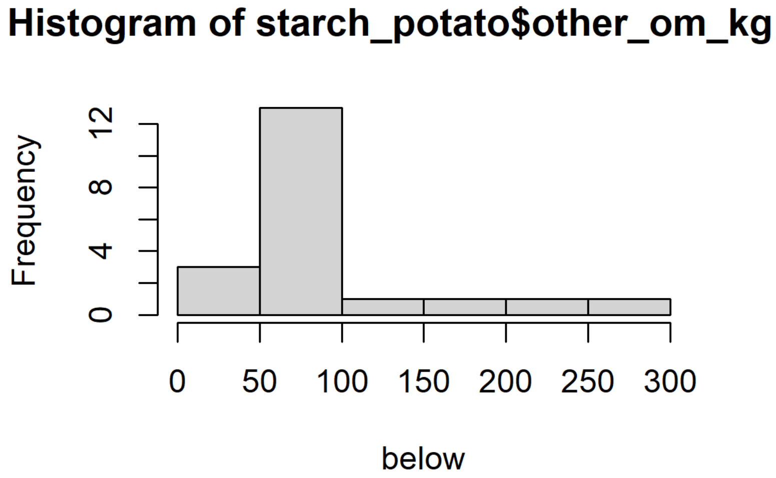

```
Analysis of Variance Table

Response: belowground_om_kg_ha
                Df Sum Sq Mean Sq F value   Pr(>F)
cultivar_variety  4  78297   19574  6.6579 0.002743 **
Residuals        15  44100    2940
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall    350 12.1 15      324      376
```

```
Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```



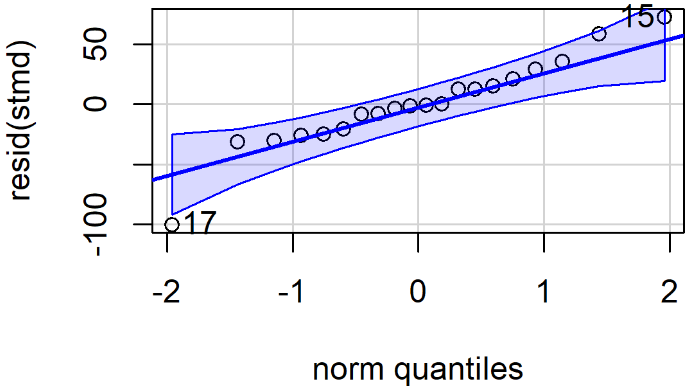

```
21 23
11 13

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.1511, p-value = 0.6962
alternative hypothesis: two-sided
```

Baby potatoes




```
 256.7170 243.0618
Analysis of Variance Table

Response: other_om_kg_ha
                 Df Sum Sq Mean Sq F value   Pr(>F)
cultivar_variety  4  43941 10985.4  6.4365 0.003191 **
Residuals        15  25601  1706.7
```

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   92.7 9.24 15       73      112

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```

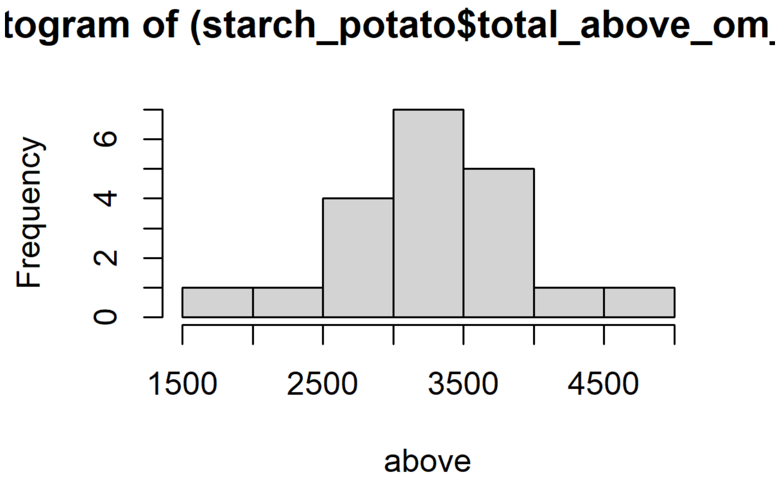



```
17 15
 7  5

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.14667, p-value = 0.7294
alternative hypothesis: two-sided
```

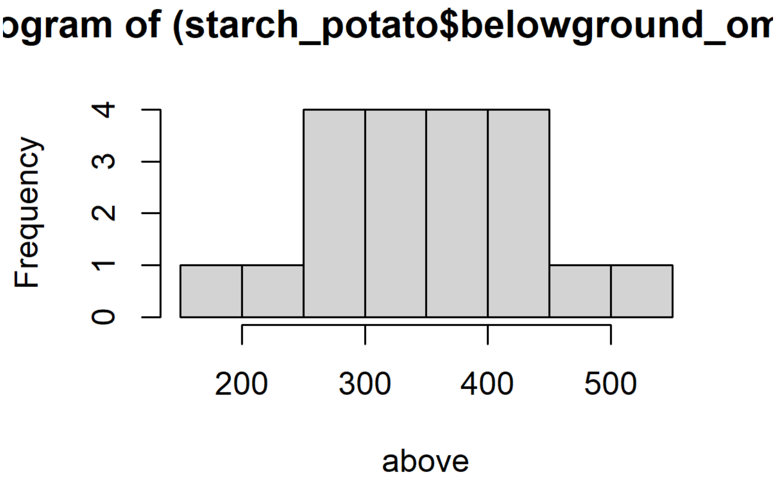
Summary and statistical testing

```
# Aboveground
sum(!is.na(starch_potato$total_above_om_kg_ha))
 20
## IQR
summary(starch_potato$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   1991    2933    3220    3260    3690    4626
# Belowground
sum(!is.na(starch_potato$belowground_om_kg_ha))
 20
## IQR
summary(starch_potato$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  190.7   299.4   352.7   350.3   409.2   502.0
# Baby potatoes
sum(!is.na(starch_potato$other_om_kg_ha))
 20
## IQR
summary(starch_potato$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  33.47   53.66   79.35   92.67   93.93  256.72
# Statistical testing

## Aboveground
```

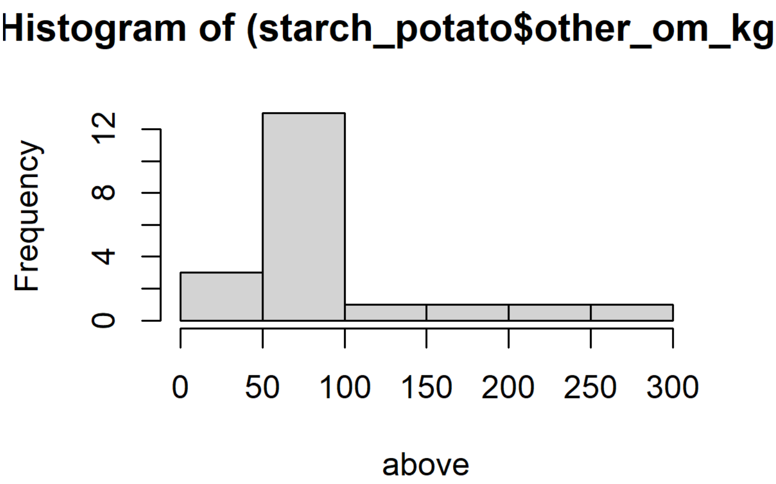
```
   Shapiro-Wilk normality test

data:  starch_potato$total_above_om_kg_ha
W = 0.99032, p-value = 0.9985
```




```
   One Sample t-test

data:  starch_potato$total_above_om_kg_ha
t = -1.6541, df = 19, p-value = 0.1145
alternative hypothesis: true mean is not equal to 3500
95 percent confidence interval:
 2955.814 3563.741
sample estimates:
mean of x
 3259.777
# Belowground

   Shapiro-Wilk normality test

data:  starch_potato$belowground_om_kg_ha
W = 0.98648, p-value = 0.9892
```




```
   One Sample t-test

data:  starch_potato$belowground_om_kg_ha
t = -8.3422, df = 19, p-value = 8.947e-08
alternative hypothesis: true mean is not equal to 500
95 percent confidence interval:
 312.7178 387.8452
sample estimates:
mean of x
 350.2815
# Baby potatoes

   Shapiro-Wilk normality test

data:  starch_potato$other_om_kg_ha
W = 0.75092, p-value = 0.0001747

   Shapiro-Wilk normality test

data:  log(starch_potato$other_om_kg_ha)
W = 0.93676, p-value = 0.2081
```

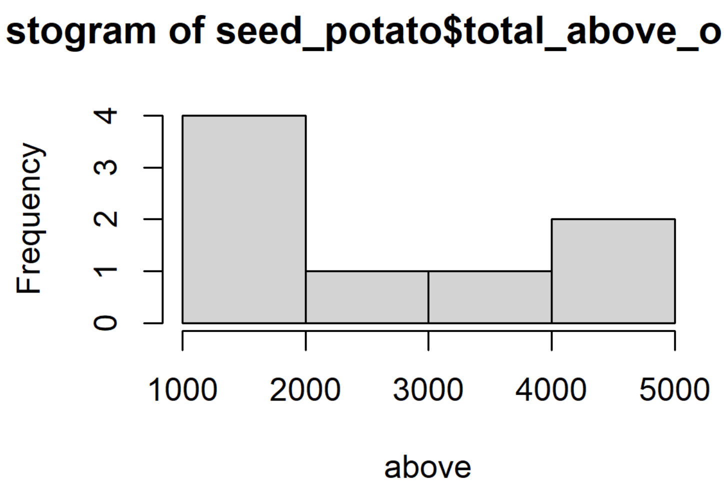


```
wilcox.test(starch_potato$other_om_kg_ha, mu = 400, alternative = "two.sided")

	Wilcoxon signed rank exact test

data:  starch_potato$other_om_kg_ha
V = 0, p-value = 1.907e-06
alternative hypothesis: true location is not equal to 400
```

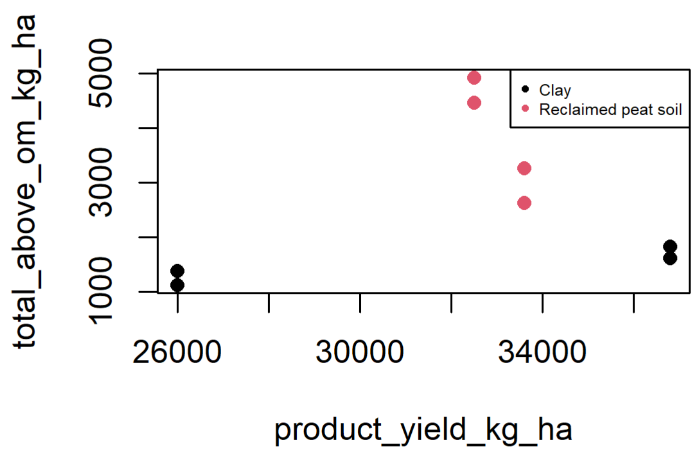
6.10 Seed potato

Aboveground

```
# Distribution
```




```
# Plot of yield vs aboveground biomass
```



No relationship with yield, too little data

Linear model analysis not applicable

Belowground

Only four datapoints available.

Baby potatoes

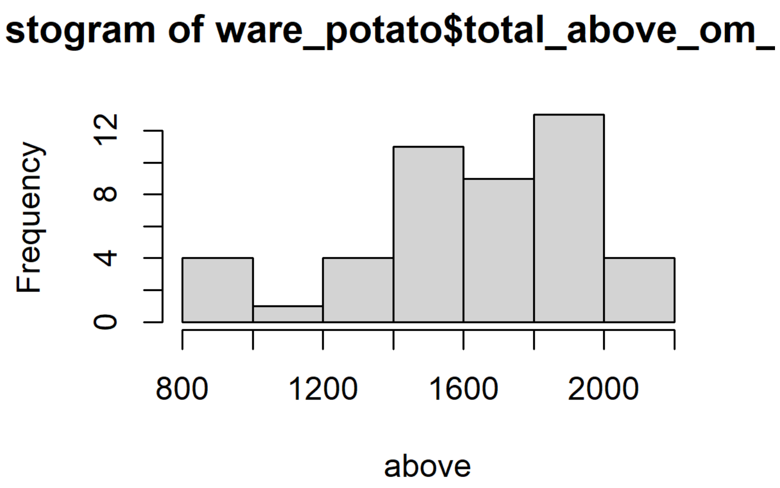
No data available.

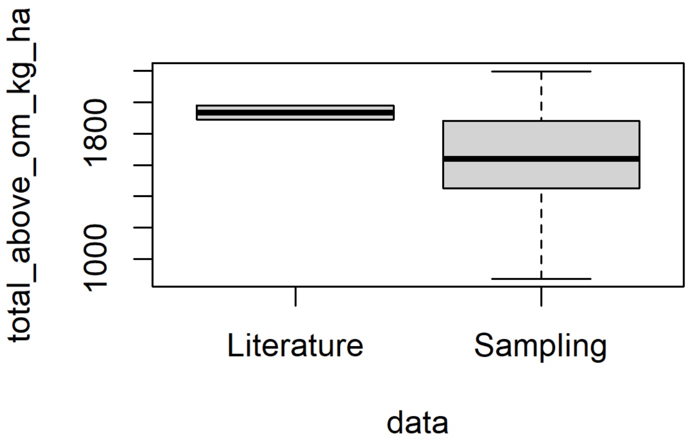
Summary and statistical testing

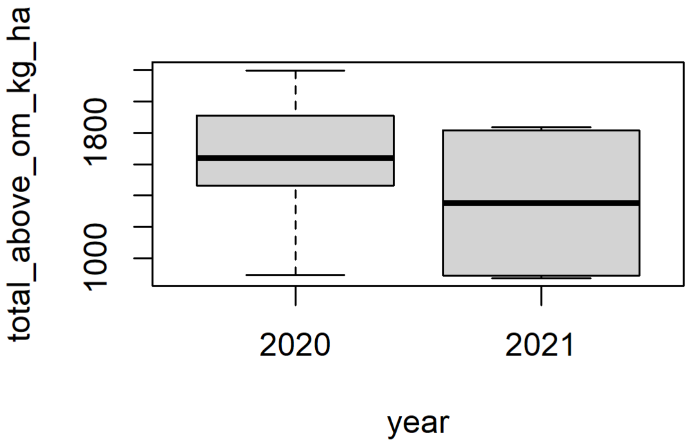
```
# Aboveground
sum(!is.na(seed_potato$total_above_om_kg_ha))
 8
## IQR
summary(seed_potato$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
   1126    1561    2222    2650    3556    4913 
## Weighted meean
weighted.mean(seed_potato$total_above_om_kg_ha, seed_potato$weights_above, na.rm = TRUE)
 2649.778
# Belowground
sum(!is.na(seed_potato$belowground_om_kg_ha))
 4
## Weighted mean
weighted.mean(seed_potato$belowground_om_kg_ha, seed_potato$weights_below, na.rm = TRUE)
 361.5275
## IQR
summary(seed_potato$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
  248.4   255.2   358.7   361.5   465.0   480.3       4 
# Baby potato
# No data

# Statistical testing not possible due to low sample size
```

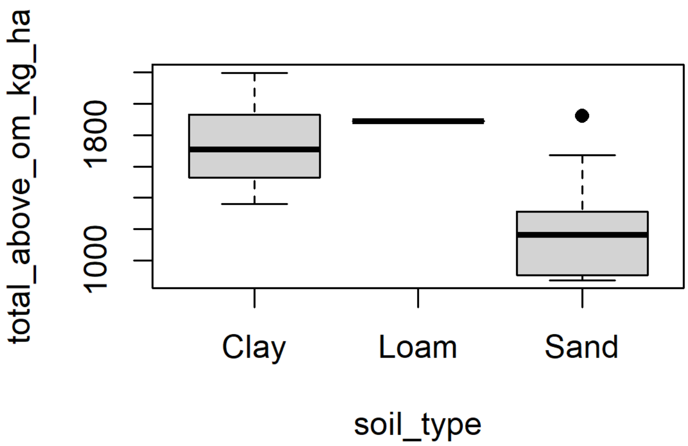
6.11 Ware potato

Aboveground

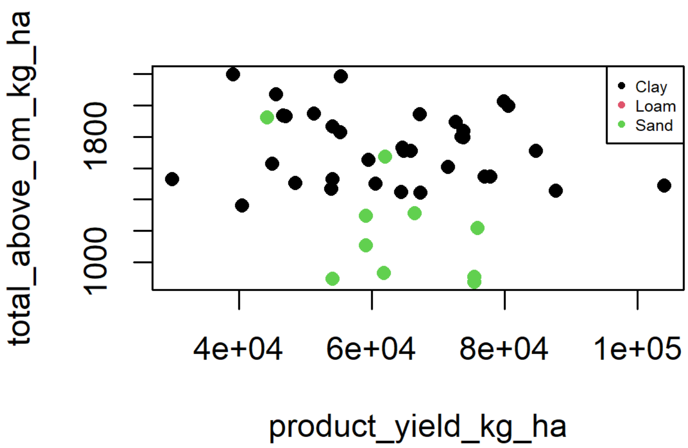

stogram of ware_potato$total_above_om_
Frequency
0
4
8
12
800
1200
1600
2000
above


total_above_om_kg_ha
1000
1800
Literature
Sampling
data

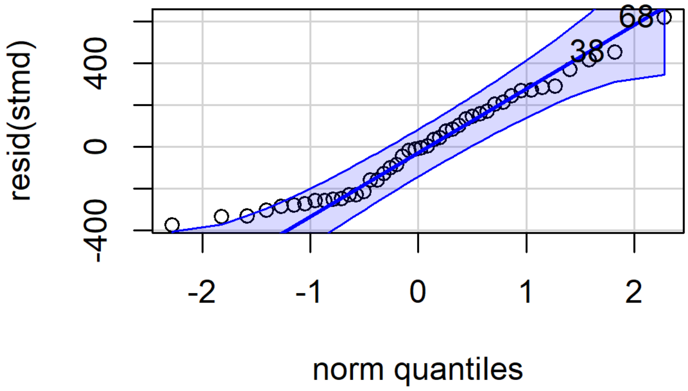




Mean of literature data: 387

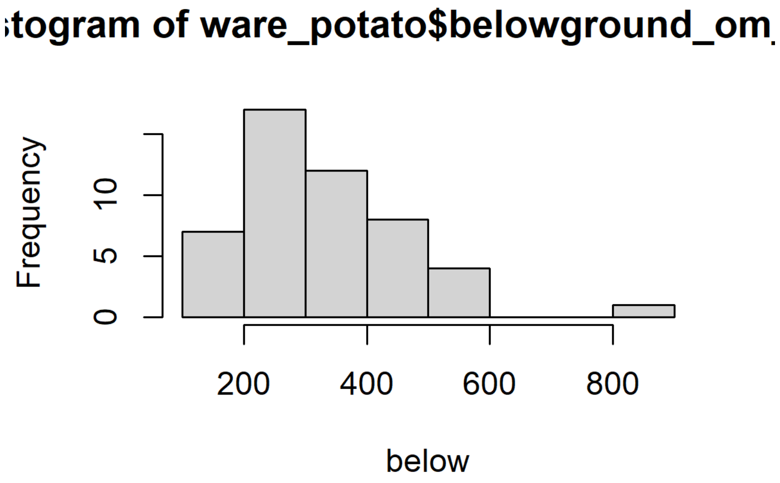


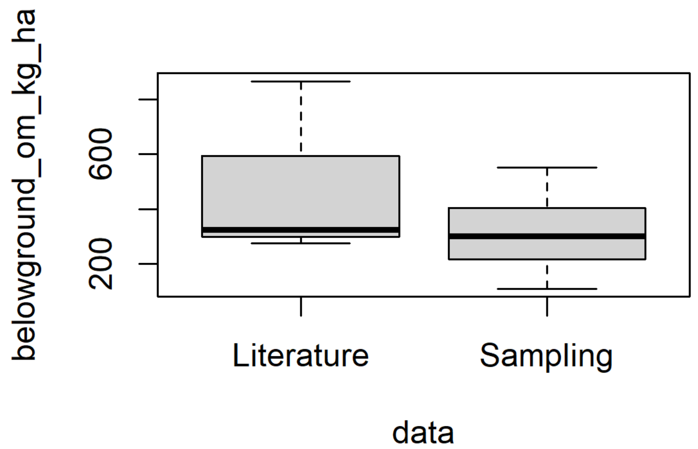
```
Analysis of Variance Table

Response: total_above_om_kg_ha
                Df  Sum Sq Mean Sq F value    Pr(>F)
year             1  296643  296643  3.8985   0.05626 .
soil_type        1 1836073 1836073 24.1296 2.091e-05 ***
cultivar_variety  6  152565   25427  0.3342   0.91423
Residuals       35 2663225   76092
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean SE df lower.CL upper.CL
 overall   1397 97 35     1200     1594

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```

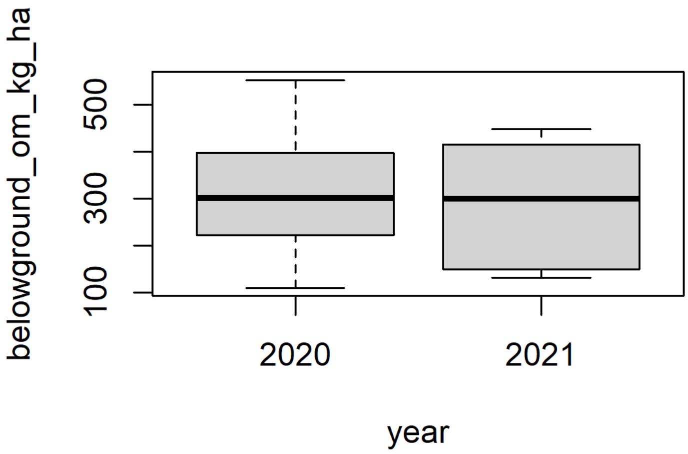


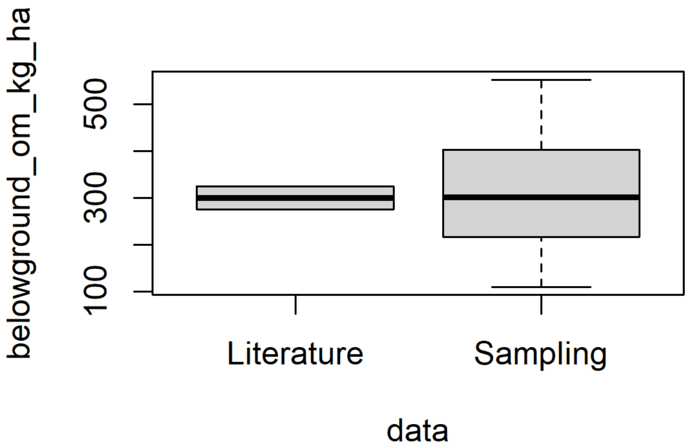

```
68 38
37  7

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.12385, p-value = 0.4722
alternative hypothesis: two-sided
```

Belowground

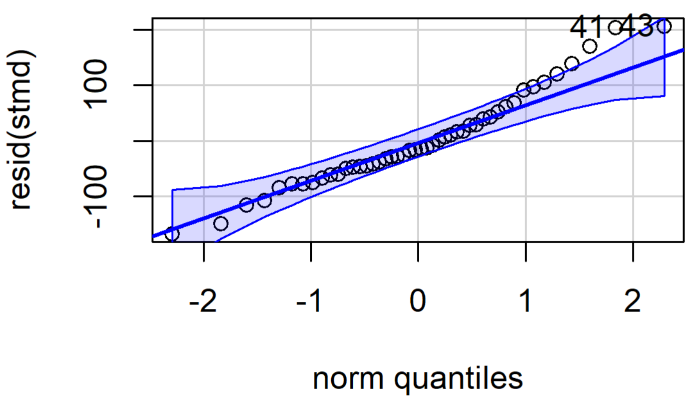

stogram of ware_potato$belowground_om
Frequency
0
5
10
200
400
600
800
below


belowground_om_kg_ha
200
600
Literature
Sampling
data



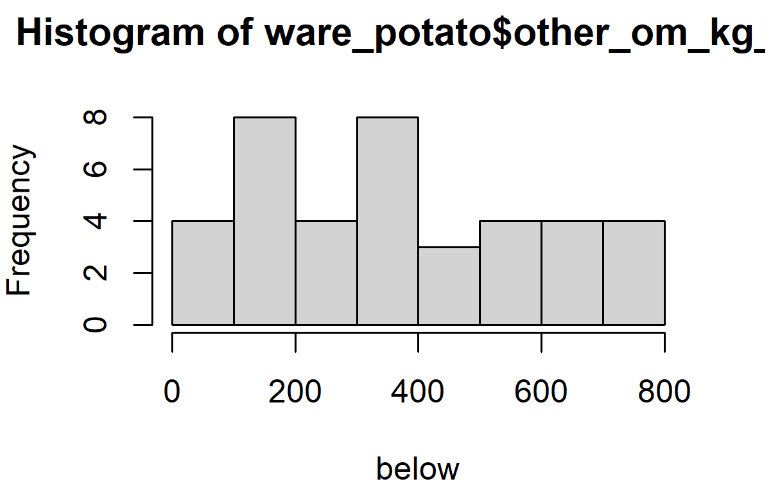



```
Analysis of Variance Table

Response: belowground_om_kg_ha
              Df Sum Sq Mean Sq F value   Pr(>F)
year             1   3491    3491  0.4048 0.528542
soil_type        1  43192   43192  5.0084 0.031330 *
cultivar_variety  6 247154   41192  4.7765 0.001071 **
Residuals       37 319089    8624
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall    268 30.5 37      206      330

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



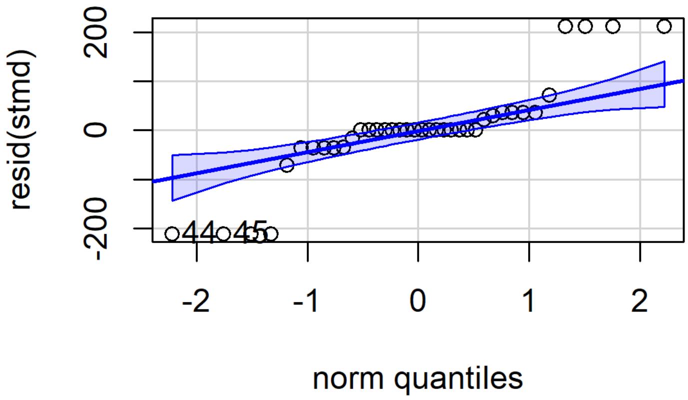

```
43 41
12 10

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.10707, p-value = 0.6285
alternative hypothesis: two-sided
```

Baby potatoes




```
Analysis of Variance Table

Response: other_om_kg_ha
              Df  Sum Sq Mean Sq F value    Pr(>F)
year           1    2355    2355  0.1869    0.6686
soil_type      1      81      81  0.0065    0.9365
cultivar_variety  5 1453496  290699 23.0718 1.874e-09 ***
Residuals     30  377993   12600
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
 1       emmean SE df lower.CL upper.CL
 overall    420 41 30      337      504

Results are averaged over the levels of: soil_type, cultivar_variety, year
Confidence level used: 0.95
```

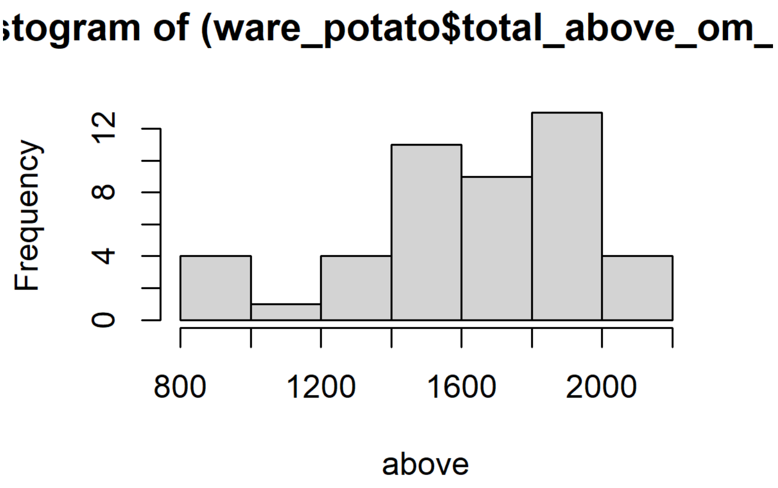



```
44 45
13 14

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.23037, p-value = 0.03543
alternative hypothesis: two-sided
```

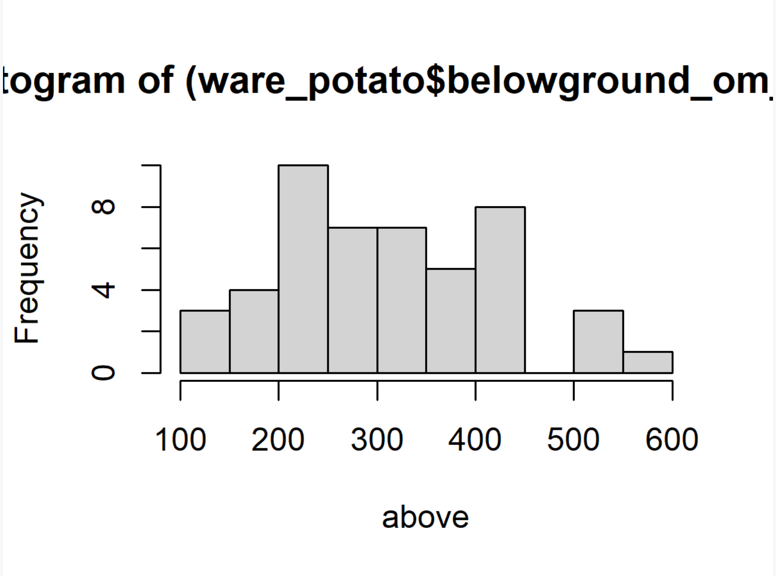
Summary and statistical testing

```
# Aboveground
sum(!is.na(ware_potato$total_above_om_kg_ha))
 46
## IQR
summary(ware_potato$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  872.5  1457.5  1662.0  1625.9  1893.4  2196.3       3
# Belowground
sum(!is.na(ware_potato$belowground_om_kg_ha))
 48
## IQR
summary(ware_potato$belowground_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  109.6   223.2   300.5   312.2   395.1   551.4       1
# Baby potatoes
sum(!is.na(ware_potato$other_om_kg_ha))
 39
## IQR
summary(ware_potato$other_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  99.22  170.63  368.00  380.14  557.14  736.62      10
## Mean
mean(ware_potato$other_om_kg_ha,na.rm=TRUE)
 380.1398
median(ware_potato$other_om_kg_ha,na.rm=TRUE)
 368.0015
```

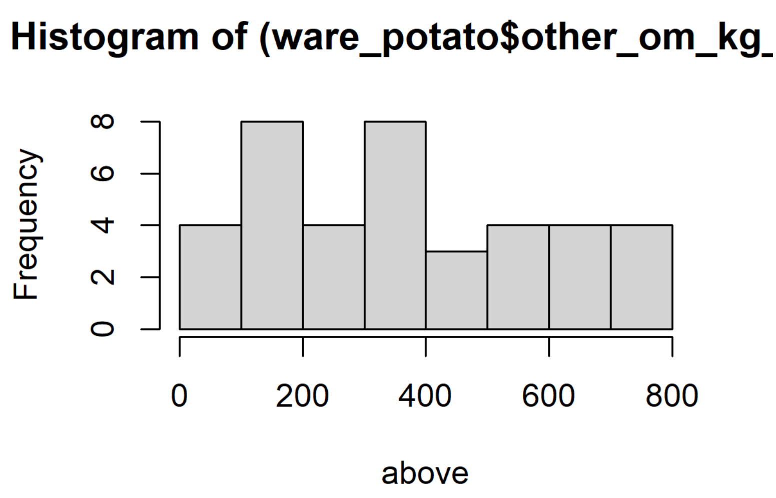
```
# Statistical testing

## Aboveground

    Shapiro-Wilk normality test

data:  ware_potato$total_above_om_kg_ha
W = 0.95103, p-value = 0.05139
```




```
    One Sample t-test

data:  ware_potato$total_above_om_kg_ha
t = -21.529, df = 45, p-value < 2.2e-16
alternative hypothesis: true mean is not equal to 2700
95 percent confidence interval:
 1525.420 1726.388
sample estimates:
mean of x
 1625.904
# Belowground

    Shapiro-Wilk normality test

data:  ware_potato$belowground_om_kg_ha
W = 0.96764, p-value = 0.2047
```




```
    One Sample t-test

data:  ware_potato$belowground_om_kg_ha
t = -11.379, df = 47, p-value = 4.215e-15
alternative hypothesis: true mean is not equal to 500
95 percent confidence interval:
 279.0018 345.4058
sample estimates:
mean of x
 312.2038
# Baby potatoes

    Shapiro-Wilk normality test

data:  ware_potato$other_om_kg_ha
W = 0.89831, p-value = 0.001974
    Shapiro-Wilk normality test

data:  log(ware_potato$other_om_kg_ha)
W = 0.9114, p-value = 0.00476
```

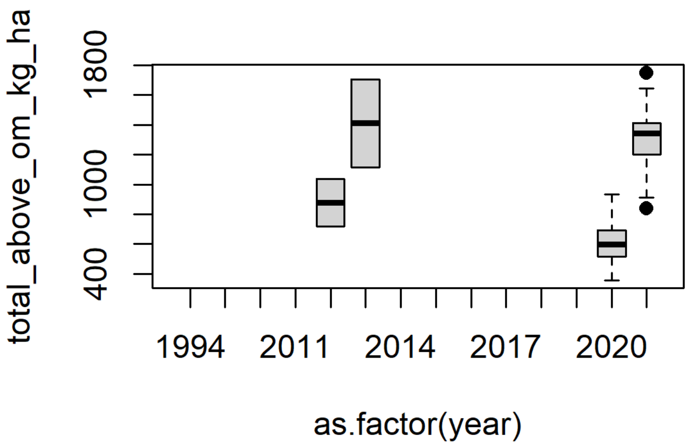


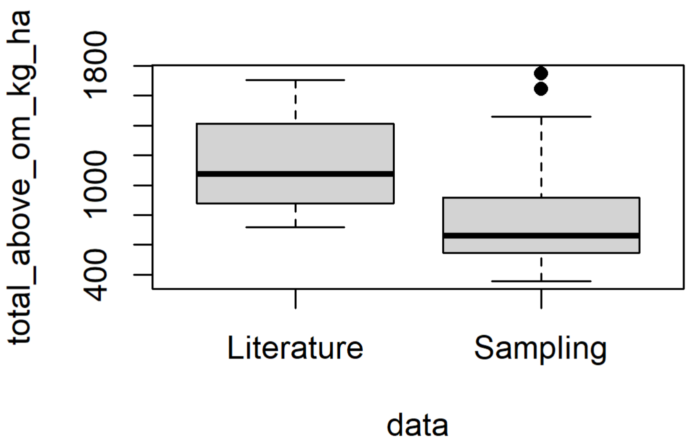

```
wilcox.test(ware_potato$other_om_kg_ha, mu = 800, alternative = "two.sided")
```

```
  Wilcoxon signed rank test with continuity correction

data:  ware_potato$other_om_kg_ha
V = 0, p-value = 5.305e-08
alternative hypothesis: true location is not equal to 800
```

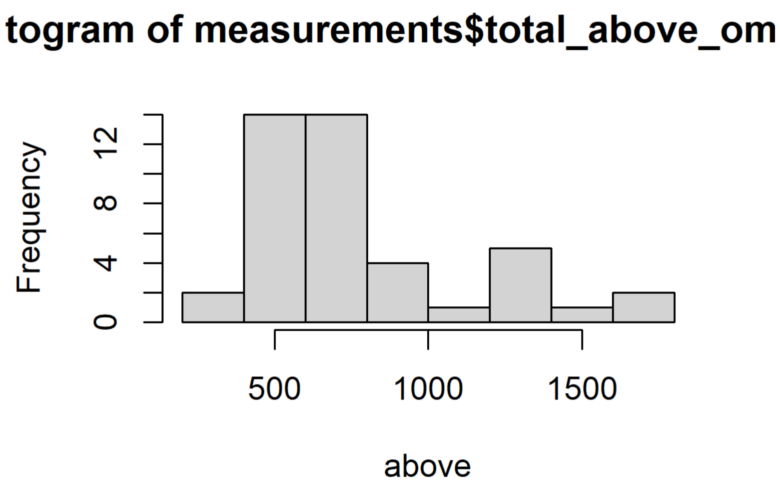
6.12 Silage maize

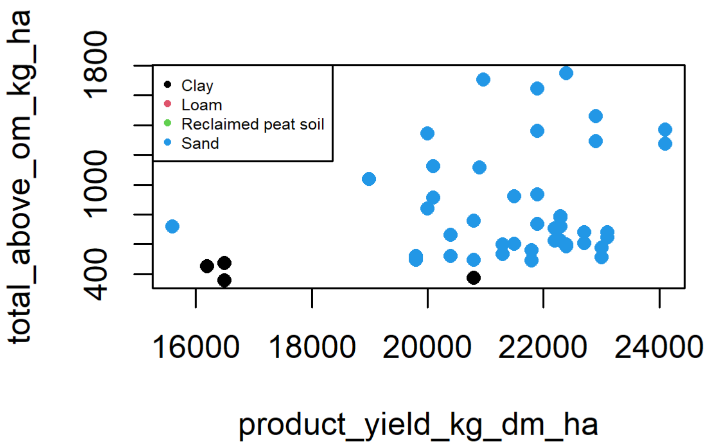
Aboveground

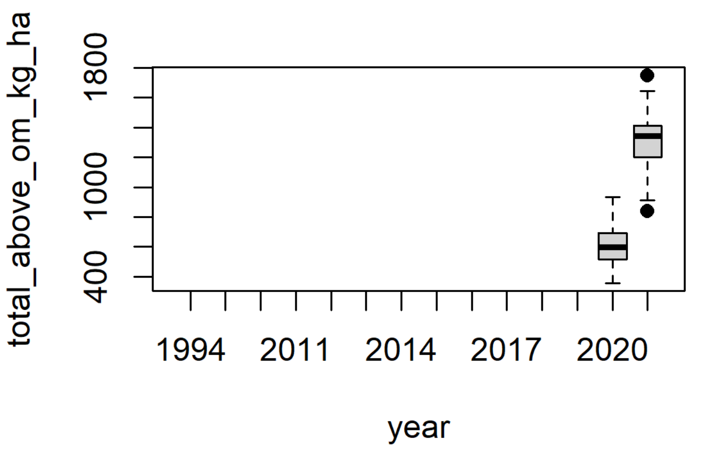





```
Mean of literature data: 343.35
Mean of measured data: 236.7618
```

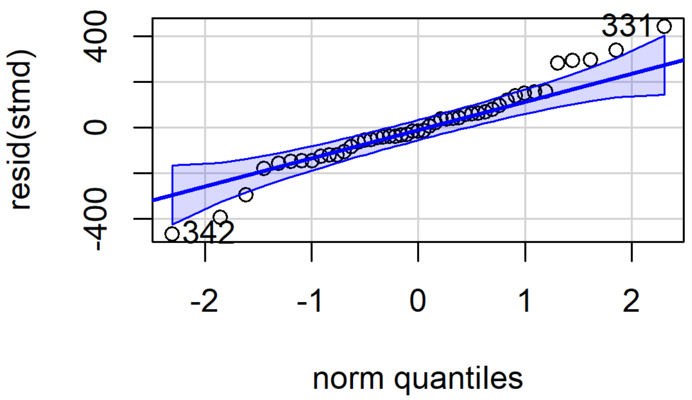






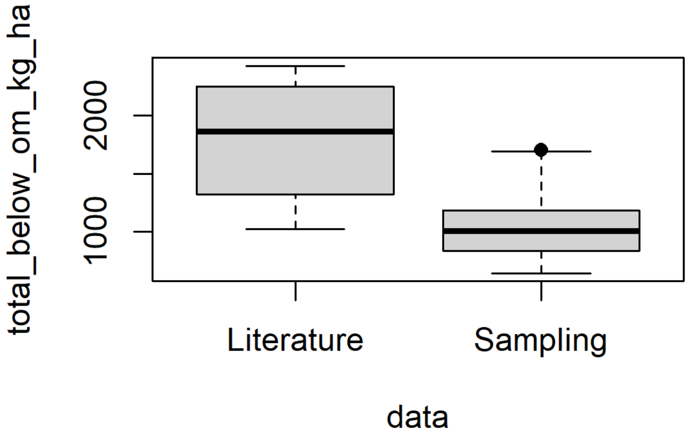

```
Analysis of Variance Table

Response: total_above_om_kg_ha
        Df  Sum Sq Mean Sq F value   Pr(>F)
```

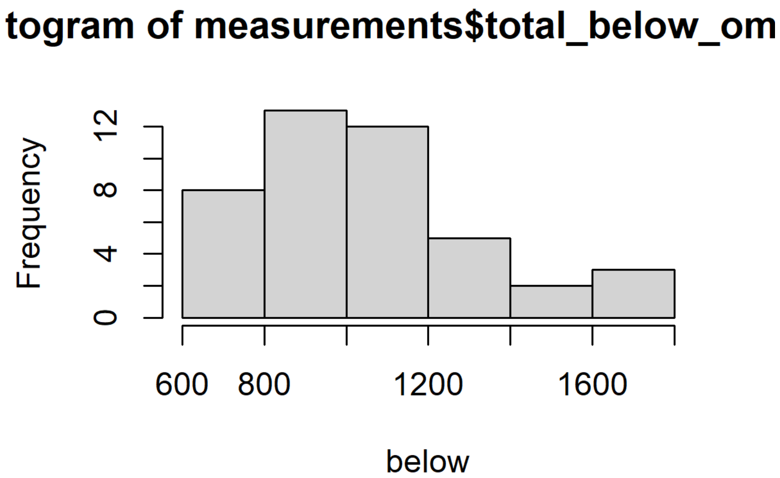
```
year       3 5982088 1994029 46.0089 2.47e-13 ***
soil_type  1  181603  181603  4.1902  0.04695 *
Residuals 42 1820284   43340
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall    945 62.9 42      818     1072

Results are averaged over the levels of: year, soil_type
Confidence level used: 0.95
```



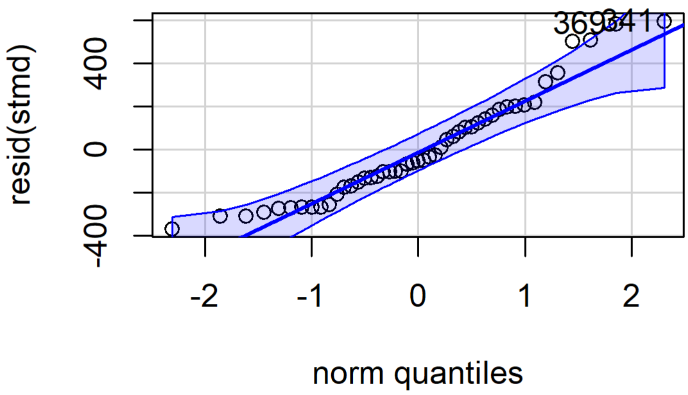

```
342 331
 16   5

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.095765, p-value = 0.7458
alternative hypothesis: two-sided
```

Belowground





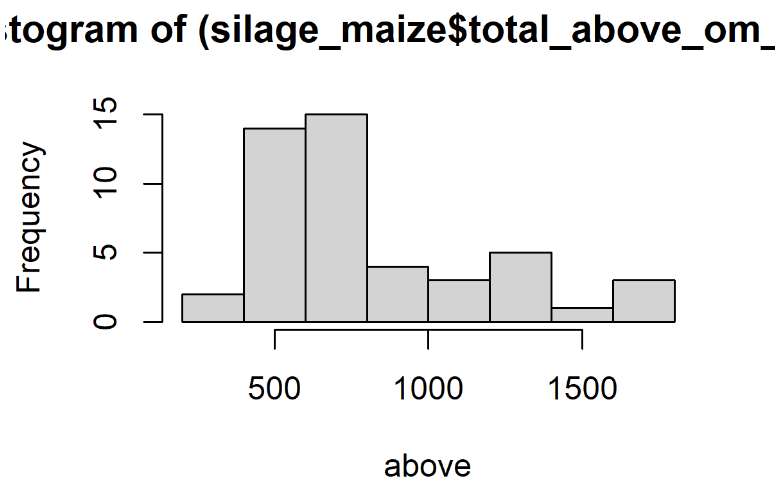

```
Analysis of Variance Table

Response: total_below_om_kg_ha
          Df   Sum Sq Mean Sq F value    Pr(>F)    
year       3 12799211 4266404 59.5485 3.534e-15 ***
soil_type  1   263207  263207  3.6737    0.0621 .  
Residuals 42  3009128   71646                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   1472 80.9 42     1309     1635

Results are averaged over the levels of: year, soil_type 
Confidence level used: 0.95 
```



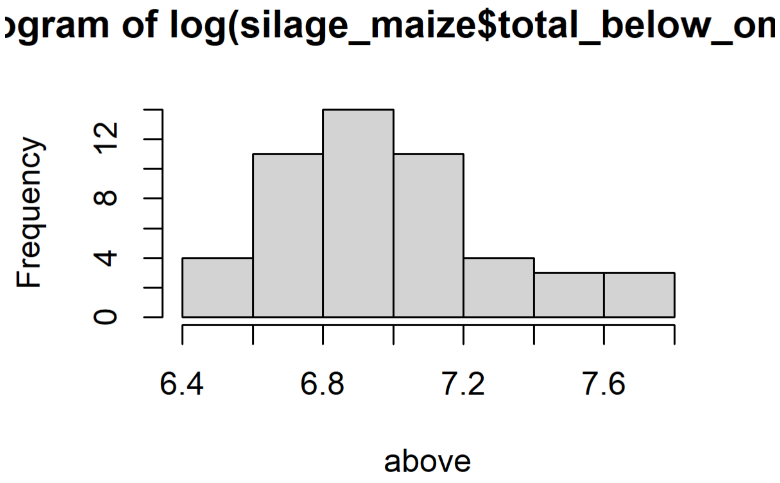

```
341 369
 15  43

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.11737, p-value = 0.4997
alternative hypothesis: two-sided
```

Summary and statistical testing

```
# Aboveground
sum(!is.na(silage_maize$total_above_om_kg_ha))
 47
## IQR
summary(silage_maize$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
  357.5   565.4   680.8   819.4   983.9  1747.0       3 
# Belowground
sum(!is.na(silage_maize$total_below_om_kg_ha))
 50
## IQR
summary(silage_maize$total_below_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  646.7   839.2  1050.7  1144.3  1287.0  2421.0 
# Statistical testing

## Aboveground
```



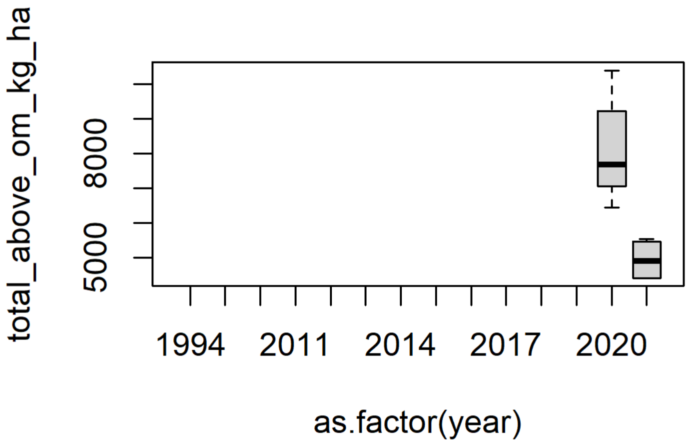

```
    Shapiro-Wilk normality test

data:  silage_maize$total_above_om_kg_ha
W = 0.86617, p-value = 7.074e-05
    Shapiro-Wilk normality test

data:  sqrt(silage_maize$total_above_om_kg_ha)
W = 0.91276, p-value = 0.001888

    Shapiro-Wilk normality test

data:  log(silage_maize$total_above_om_kg_ha)
W = 0.94887, p-value = 0.03912
# Data does not follow the normal distribution.


    Wilcoxon signed rank exact test

data:  silage_maize$total_above_om_kg_ha
V = 1067, p-value = 1.616e-09
alternative hypothesis: true location is not equal to 500
## Belowground

    Shapiro-Wilk normality test

data:  silage_maize$total_below_om_kg_ha
W = 0.86639, p-value = 4.434e-05
    Shapiro-Wilk normality test

data:  log(silage_maize$total_below_om_kg_ha)
W = 0.95897, p-value = 0.08045
```

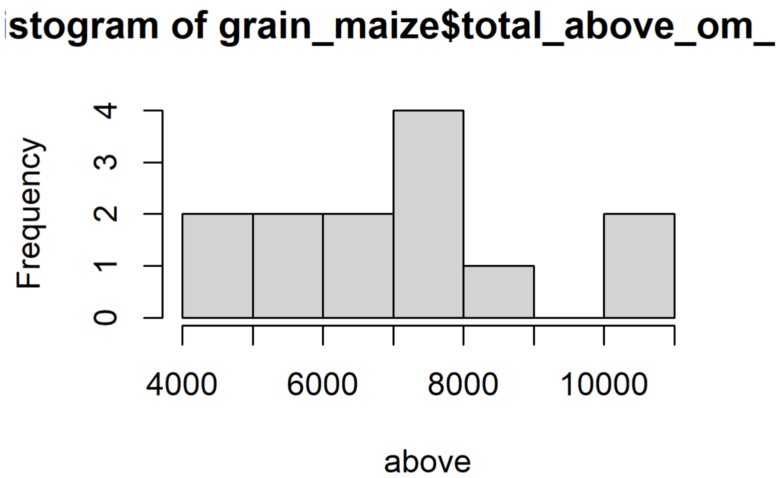


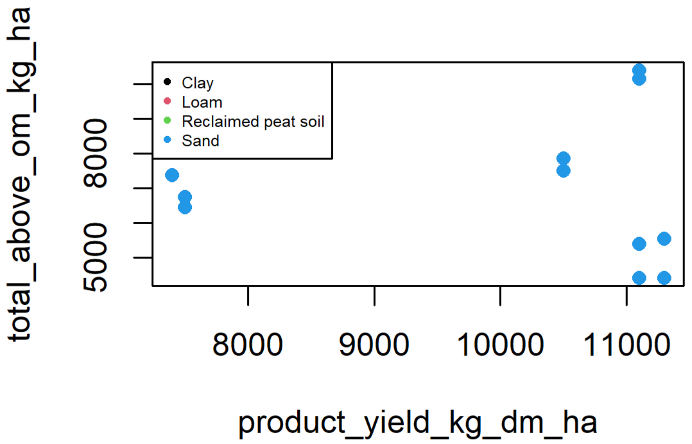

```
   One Sample t-test

data:  log(silage_maize$total_below_om_kg_ha)
t = -7.1543, df = 49, p-value = 3.827e-09
alternative hypothesis: true mean is not equal to 7.31322
95 percent confidence interval:
 6.897852 7.080026
sample estimates:
mean of x
 6.988939
```

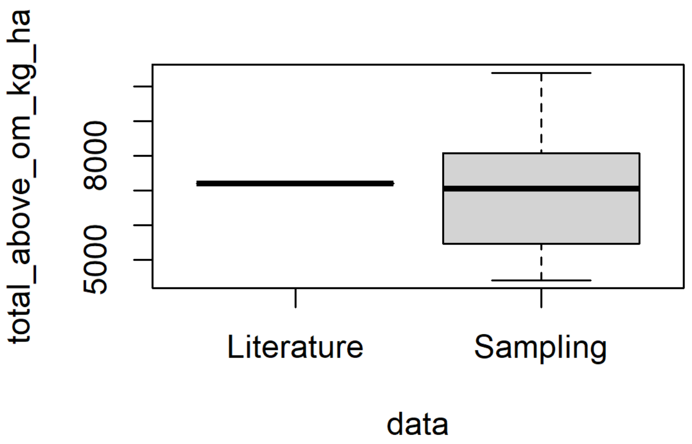
6.13 Grain maize

Aboveground

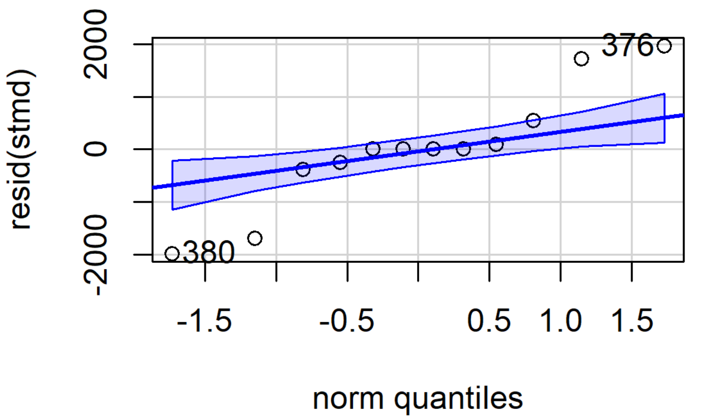

total_above_om_kg_ha
5000
8000
1994
2011
2014
2017
2020
as.factor(year)


istogram of grain_maize$total_above_om_
Frequency
0
1
2
3
4
4000
6000
8000
10000
above



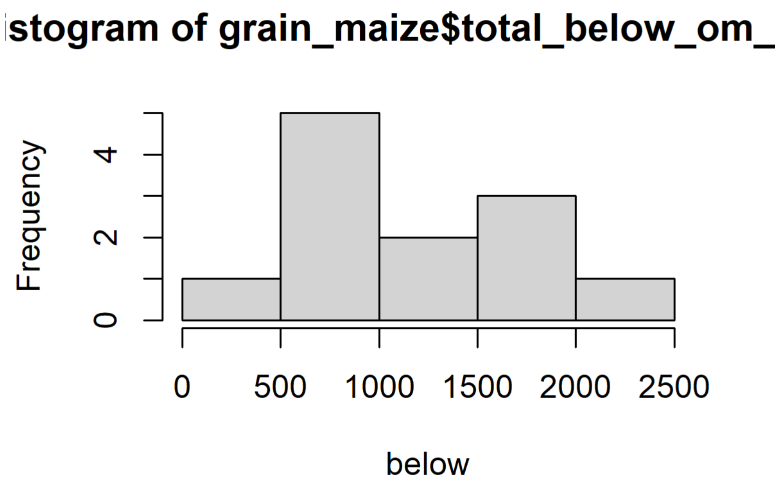



```
Analysis of Variance Table

Response: total_above_om_kg_ha
             Df   Sum Sq  Mean Sq F value  Pr(>F)
year          1 26596657 26596657 11.2911 0.01523 *
cultivar_variety  4  2020507   505127  0.2144 0.92105
Residuals     6 14133261  2355543
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   6509 470  6     5359     7659

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```



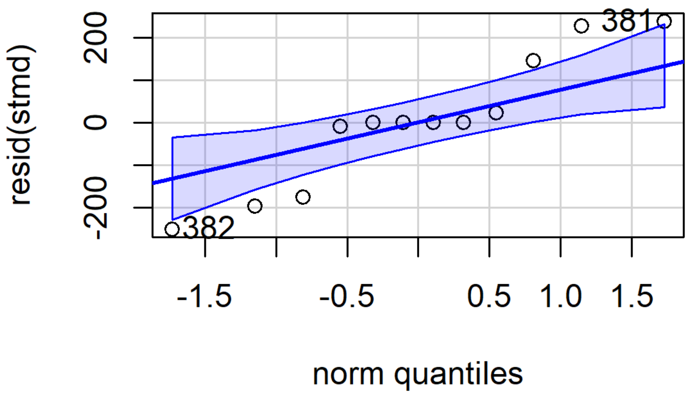

```
380 376
 6   2

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.90157, p-value = 0.1662
```

Belowground




```
Analysis of Variance Table

Response: total_below_om_kg_ha
                 Df  Sum Sq Mean Sq F value    Pr(>F)    
year              1 2682682 2682682 61.2555 0.0002297 ***
cultivar_variety  4  400500  100125  2.2862 0.1748194    
Residuals         6  262770   43795                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   1367 64.1  6     1210     1524
```

```
Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```




```
382 381
 8   7

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.90982, p-value = 0.2122
```

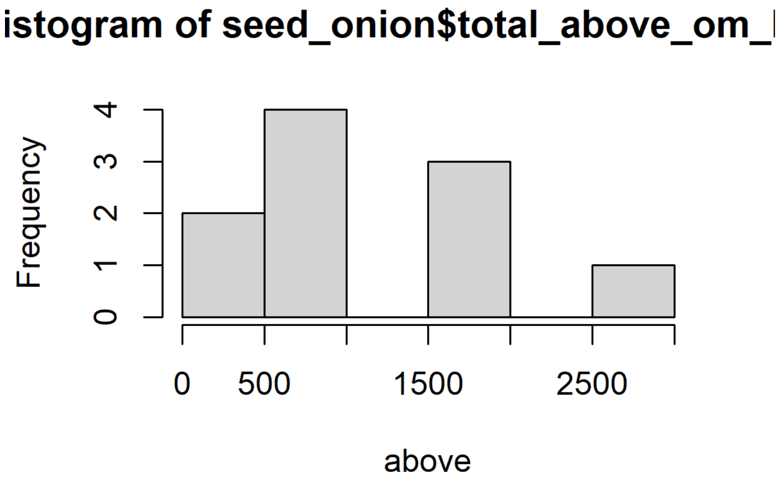
Summary and statistical testing

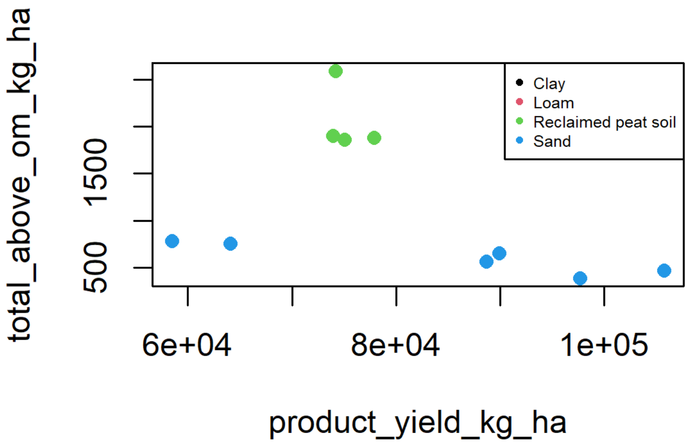
```
# Aboveground
sum(!is.na(grain_maize$total_above_om_kg_ha))
 13
## IQR
summary(grain_maize$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   4404    5528    7200    7048    7848   10383
# Belowground
sum(!is.na(grain_maize$total_below_om_kg_ha))
 12
## IQR
summary(grain_maize$total_below_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
  496.6   782.2  1056.7  1199.8  1596.7  2246.7       1
# Statistical testing

   Shapiro-Wilk normality test

data:  grain_maize$total_above_om_kg_ha
W = 0.94635, p-value = 0.5441
   One Sample t-test

data:  grain_maize$total_above_om_kg_ha
t = 2.9558, df = 12, p-value = 0.01201
alternative hypothesis: true mean is not equal to 5500
95 percent confidence interval:
 5906.846 8188.687
sample estimates:
mean of x
 7047.767
```

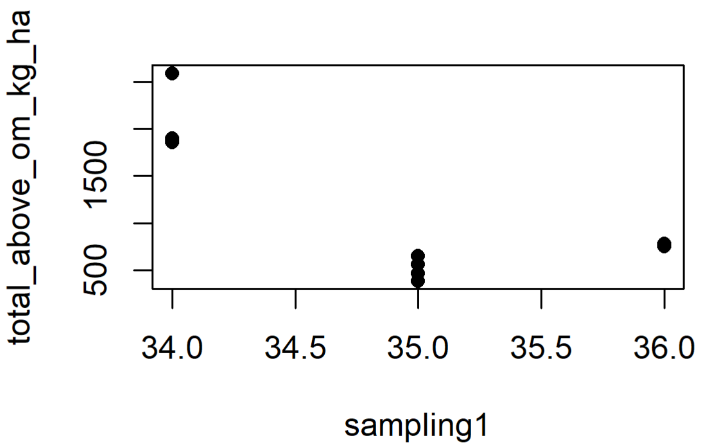
```
    Shapiro-Wilk normality test

data:  grain_maize$total_below_om_kg_ha
W = 0.91613, p-value = 0.2555
    One Sample t-test

data:  grain_maize$total_below_om_kg_ha
t = -1.8858, df = 11, p-value = 0.08598
alternative hypothesis: true mean is not equal to 1500
95 percent confidence interval:
  849.3326 1550.1744
sample estimates:
mean of x
 1199.753
```

6.14 Seed onion

Aboveground

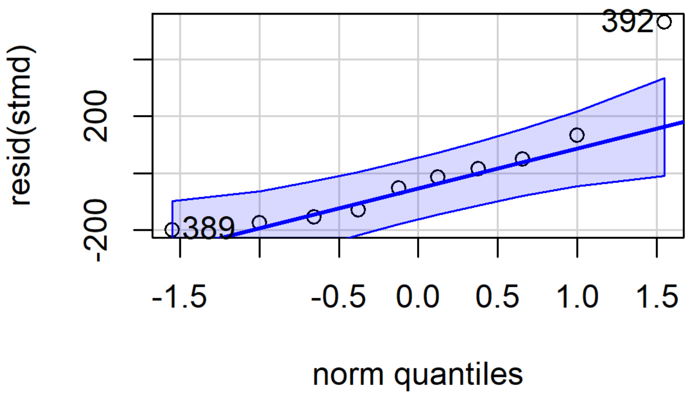






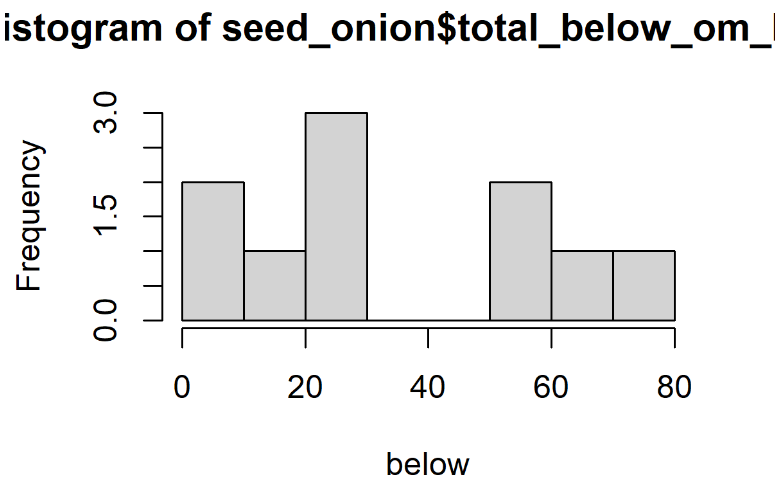

```
Analysis of Variance Table

Response: total_above_om_kg_ha
          Df  Sum Sq Mean Sq F value    Pr(>F)
```

```
soil_type        1 5076740 5076740 85.4844 3.579e-05 ***
cultivar_variety 1   81565   81565  1.3734    0.2796
Residuals        7  415715   59388
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   1347 80.6  7     1157     1538

Results are averaged over the levels of: cultivar_variety, soil_type
Confidence level used: 0.95
```

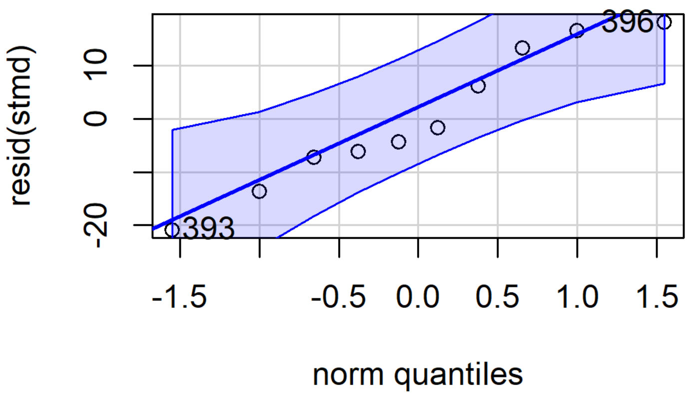



```
392 389
  4   1

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.81743, p-value = 0.02359
```

Belowground



```
Analysis of Variance Table

Response: total_below_om_kg_ha
                Df Sum Sq Mean Sq F value   Pr(>F)
soil_type        1 3402.1  3402.1 15.3611 0.005754 **
cultivar_variety  1  676.7   676.7  3.0554 0.123960
Residuals        7 1550.3   221.5
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   33.1 4.92  7     21.5     44.8

Results are averaged over the levels of: cultivar_variety, soil_type
Confidence level used: 0.95
```




```
393 396
  5   8

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.94742, p-value = 0.6381
```

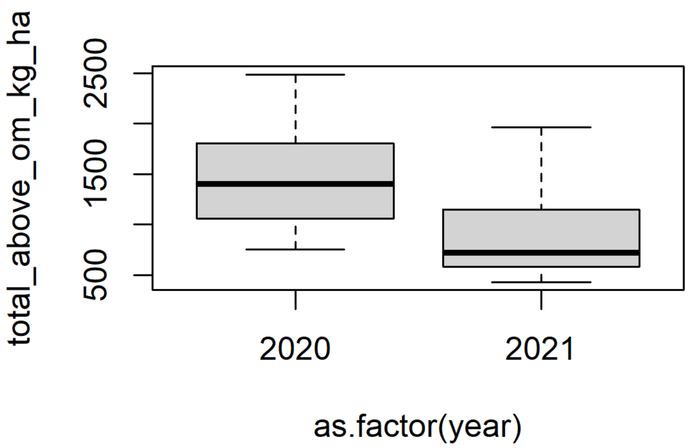
Summary and statistical testing

```
# Aboveground
sum(!is.na(seed_onion$total_above_om_kg_ha))
 10
## IQR
summary(seed_onion$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  387.7   586.7   764.5  1181.4  1873.0  2584.2
##  Mean and median
mean(seed_onion$total_above_om_kg_ha, na.rm=TRUE)
 1181.377
median(seed_onion$total_above_om_kg_ha, na.rm=TRUE)
 764.5013
# Belowground
sum(!is.na(seed_onion$total_below_om_kg_ha))
 10
## IQR
summary(seed_onion$total_below_om_kg_ha, na.rm=TRUE)
```

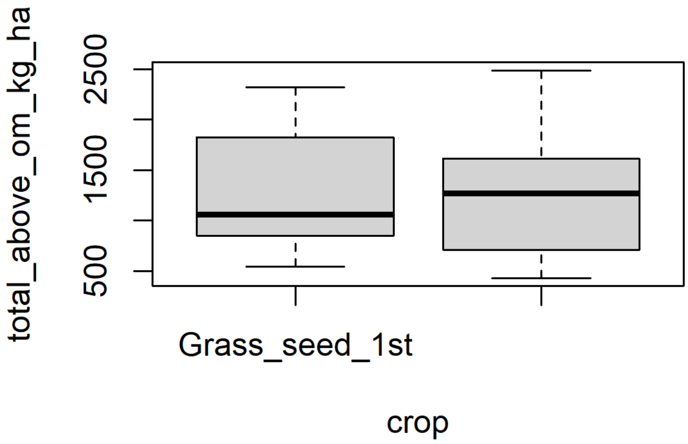
```
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  5.158  13.518  27.287  35.028  59.056  71.259 
# Statistical testing
    Shapiro-Wilk normality test

data:  seed_onion$total_above_om_kg_ha
W = 0.83876, p-value = 0.04264

    Shapiro-Wilk normality test

data:  log(seed_onion$total_above_om_kg_ha)
W = 0.8919, p-value = 0.1781
    One Sample t-test

data:  log(seed_onion$total_above_om_kg_ha)
t = -0.073398, df = 9, p-value = 0.9431
alternative hypothesis: true mean is not equal to 6.882437
95 percent confidence interval:
 6.377073 7.356038
sample estimates:
mean of x 
 6.866556 

    Shapiro-Wilk normality test

data:  seed_onion$total_below_om_kg_ha
W = 0.87725, p-value = 0.1213
    One Sample t-test

data:  seed_onion$total_below_om_kg_ha
t = -33.504, df = 9, p-value = 9.264e-11
alternative hypothesis: true mean is not equal to 300
95 percent confidence interval:
 17.13771 52.91883
sample estimates:
mean of x 
 35.02827 
```

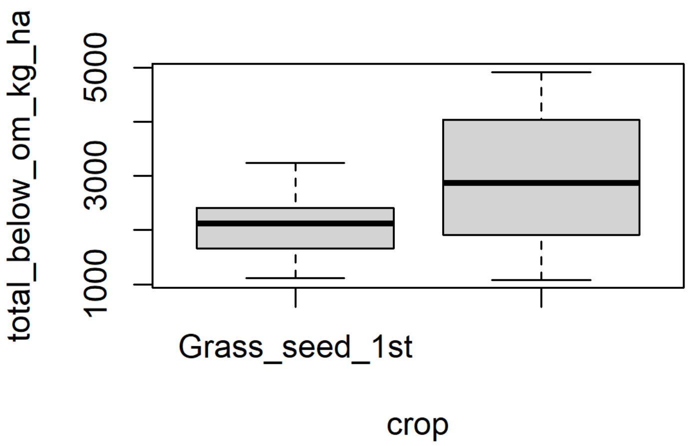
6.15 Grass seed

```
# Plot by year
```



Difference between 1st and 2nd year



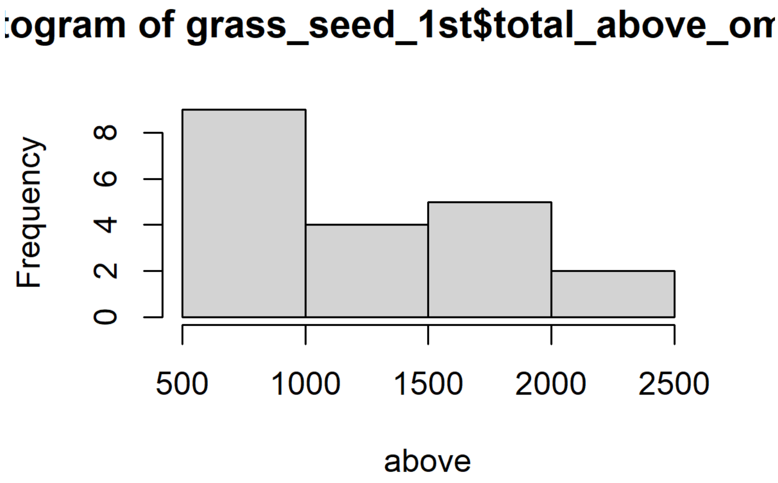


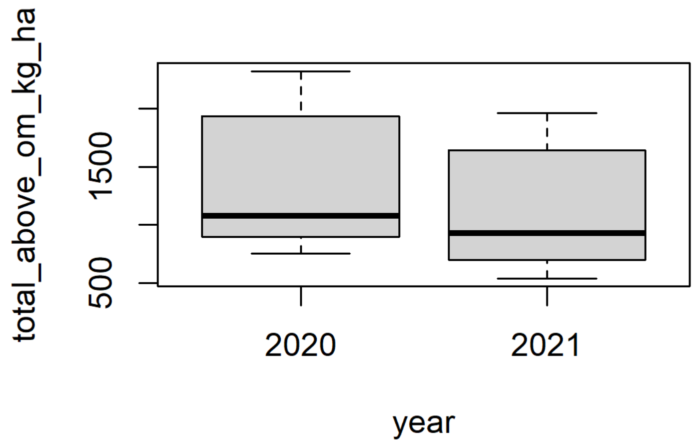

```
Statistical testing
## Aboveground

   Shapiro-Wilk normality test

data:  grass_seed$total_above_om_kg_ha
W = 0.95504, p-value = 0.1131
   Two Sample t-test

data:  total_above_om_kg_ha by crop
t = 0.17298, df = 38, p-value = 0.8636
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -325.2975  386.0839
sample estimates:
mean in group Grass_seed_1st mean in group Grass_seed_2nd
                1262.007                1231.614
# Not significantly different means

## Belowground
```

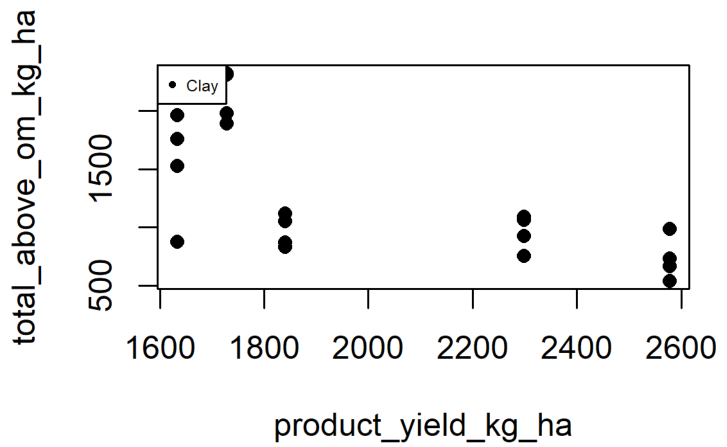
```
   Shapiro-Wilk normality test

data:  grass_seed$total_below_om_kg_ha
W = 0.92721, p-value = 0.0164
   Shapiro-Wilk normality test

data:  log(grass_seed$total_below_om_kg_ha)
W = 0.94982, p-value = 0.08781
   Two Sample t-test

data:  log(total_below_om_kg_ha) by crop
t = -1.9248, df = 36, p-value = 0.06218
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.55422799  0.01448149
sample estimates:
mean in group Grass_seed_1st mean in group Grass_seed_2nd
                7.597378                     7.867251
# Significantly different means
```

6.16 Grass seed 1st

Aboveground

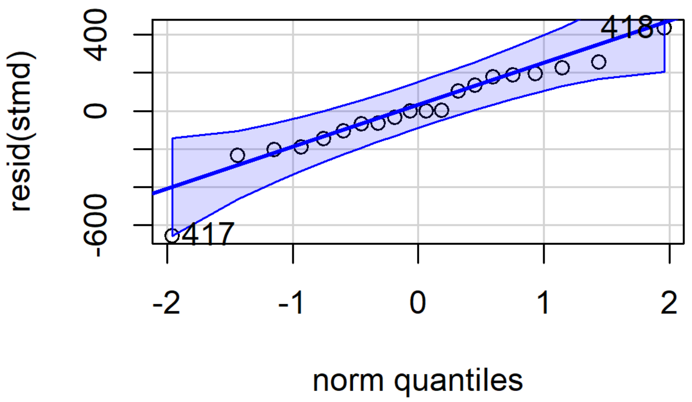






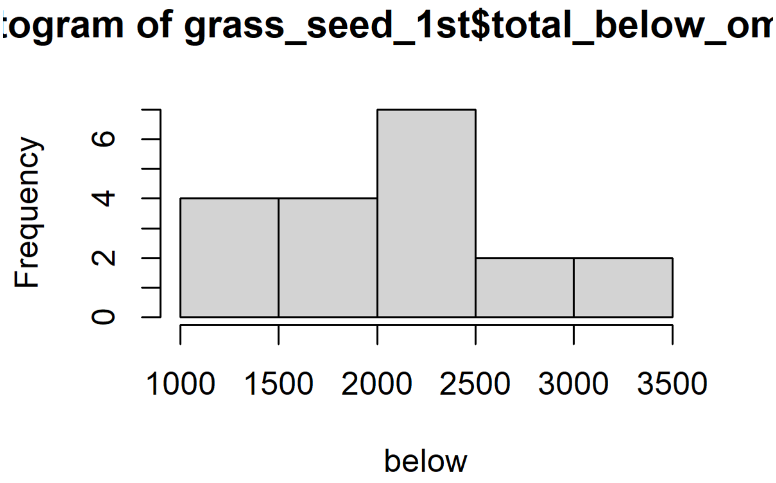

```
Call:
lm(formula = total_above_om_kg_ha ~ product_yield_kg_ha, data = grass_seed_1st,
    weights = weights_above)
```

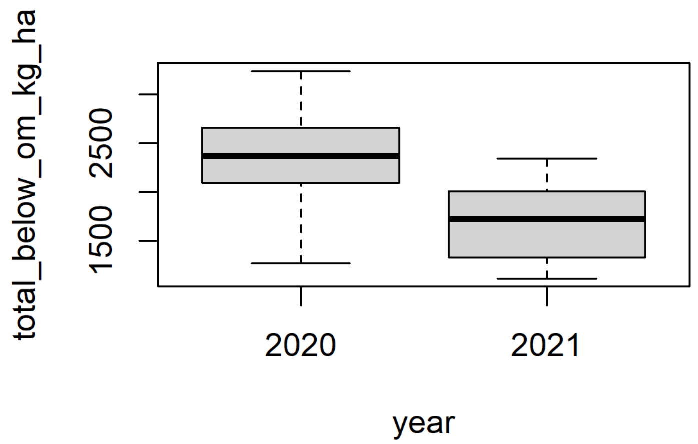
```
Residuals:
    Min      1Q  Median      3Q     Max
-784.64 -242.09   23.32  304.63  756.35

Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        3364.997    542.798   6.199 7.51e-06 ***
product_yield_kg_ha  -1.043      0.265  -3.936 0.000968 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 428.9 on 18 degrees of freedom
Multiple R-squared:  0.4626,	Adjusted R-squared:  0.4327
F-statistic: 15.49 on 1 and 18 DF,  p-value: 0.0009679
Analysis of Variance Table

Response: total_above_om_kg_ha
                 Df  Sum Sq Mean Sq F value    Pr(>F)
year              1  228330  228330  3.0691    0.1017
cultivar_variety  4 4890513 1222628 16.4337 3.483e-05 ***
Residuals        14 1041567   74398
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   1225 75.1 14     1063     1386

Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```



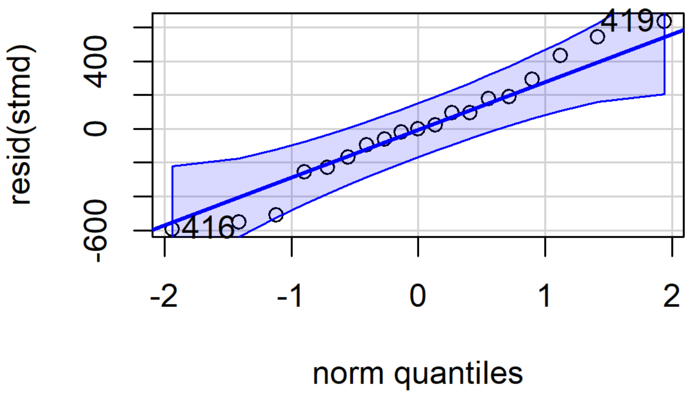

```
417 418
 18  19

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.10674, p-value = 0.9583
alternative hypothesis: two-sided
```

Belowground





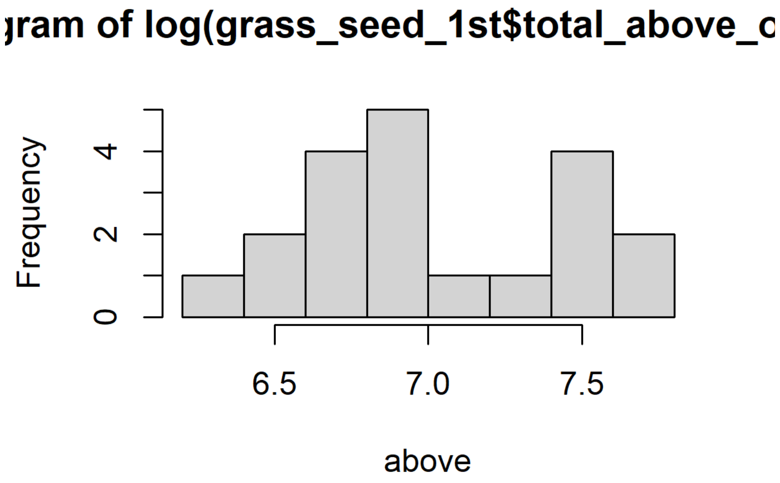

```
Analysis of Variance Table

Response: total_below_om_kg_ha
             Df  Sum Sq Mean Sq F value  Pr(>F)
year          1 1987734 1987734 12.1165 0.00406 **
cultivar_variety  4 2426718  606680  3.6981 0.03195 *
Residuals      13 2132669  164051
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   2069 116 13     1818     2320

Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```



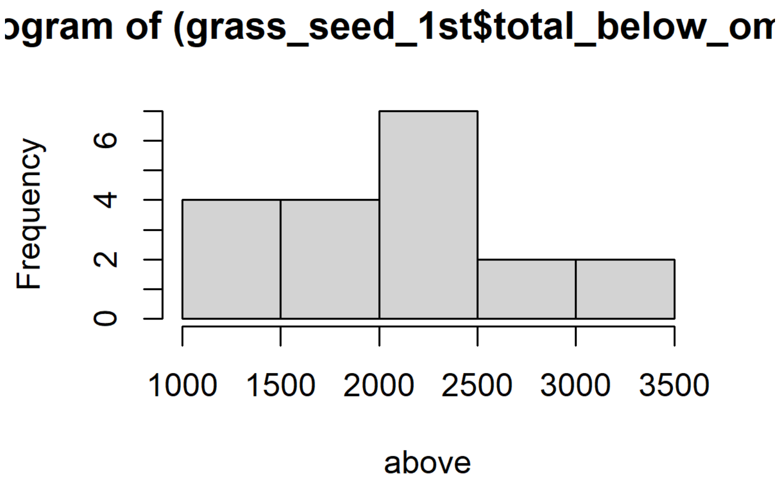

```
419 416
 19  16

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.088669, p-value = 0.9951
alternative hypothesis: two-sided
```

Summary and statistical testing

```
# Aboveground
sum(!is.na(grass_seed_1st$total_above_om_kg_ha))
 20
## IQR
summary(grass_seed_1st$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  540.2   859.8  1055.9  1262.0  1789.9  2317.9 
# Belowground
sum(!is.na(grass_seed_1st$total_below_om_kg_ha))
 19
## IQR
summary(grass_seed_1st$total_below_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   1118    1667    2123    2080    2412    3235       1 
# Statistical testing

# Aboveground

   Shapiro-Wilk normality test

data:  grass_seed_1st$total_above_om_kg_ha
W = 0.87579, p-value = 0.01487

   Shapiro-Wilk normality test

data:  log(grass_seed_1st$total_above_om_kg_ha)
W = 0.93389, p-value = 0.1834
```




```
One Sample t-test

data:  log(grass_seed_1st$total_above_om_kg_ha)
t = -7.277, df = 19, p-value = 6.643e-07
alternative hypothesis: true mean is not equal to 7.762171
95 percent confidence interval:
 6.841984 7.253078
sample estimates:
mean of x
 7.047531
# Belowground

Shapiro-Wilk normality test

data:  grass_seed_1st$total_below_om_kg_ha
W = 0.97576, p-value = 0.8827
```

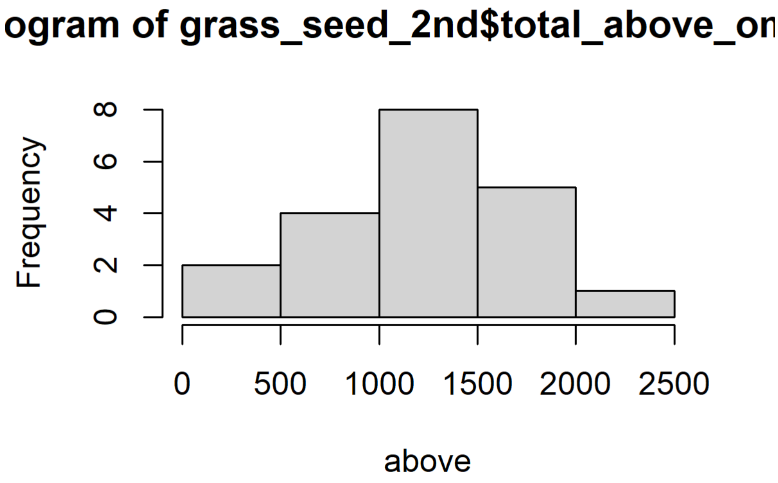


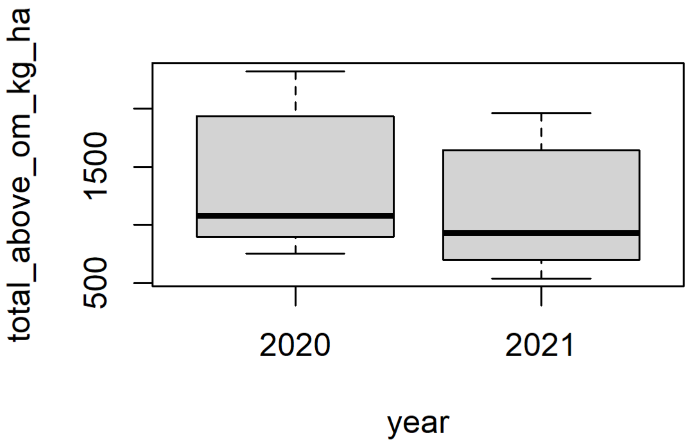

```
One Sample t-test

data:  grass_seed_1st$total_below_om_kg_ha
t = -11.347, df = 18, p-value = 1.235e-09
```

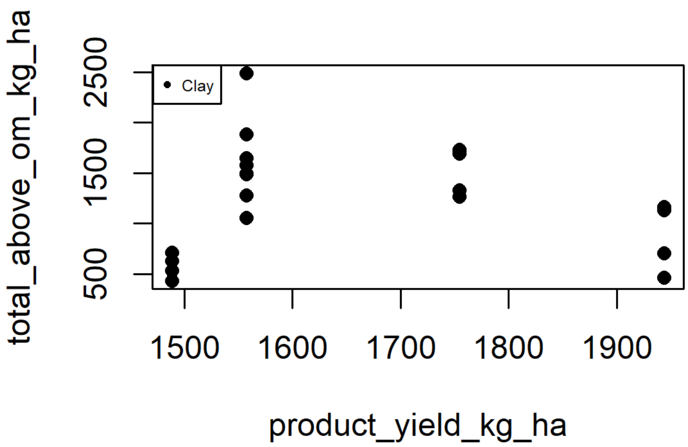
```
alternative hypothesis: true mean is not equal to 3650
95 percent confidence interval:
 1789.301 2370.670
sample estimates:
mean of x
 2079.986
```

6.17 Grass seed 2nd

Aboveground

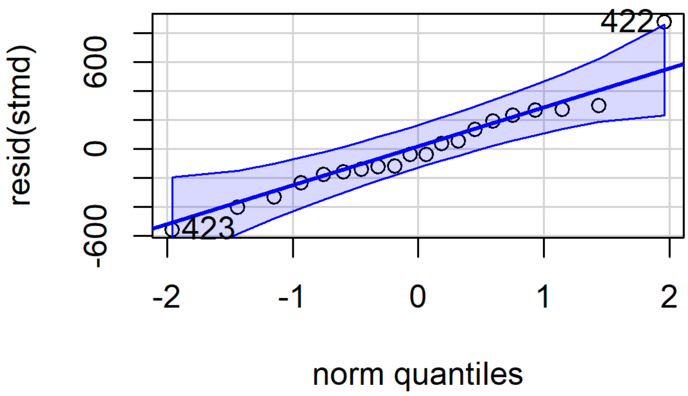






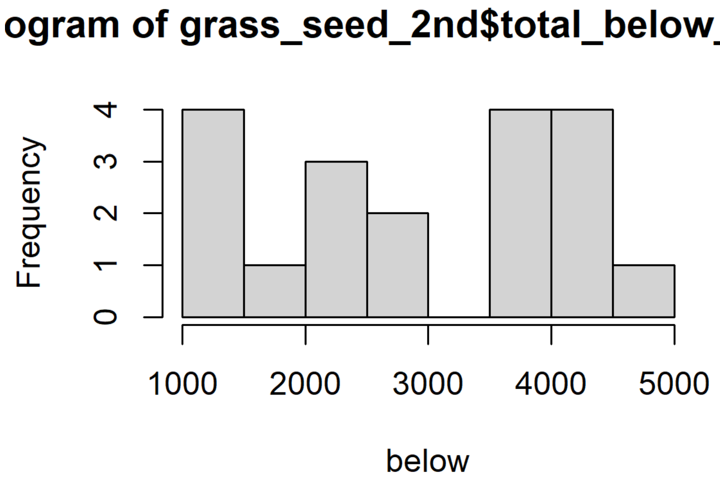

```
Analysis of Variance Table

Response: total_above_om_kg_ha
          Df  Sum Sq Mean Sq F value    Pr(>F)
```

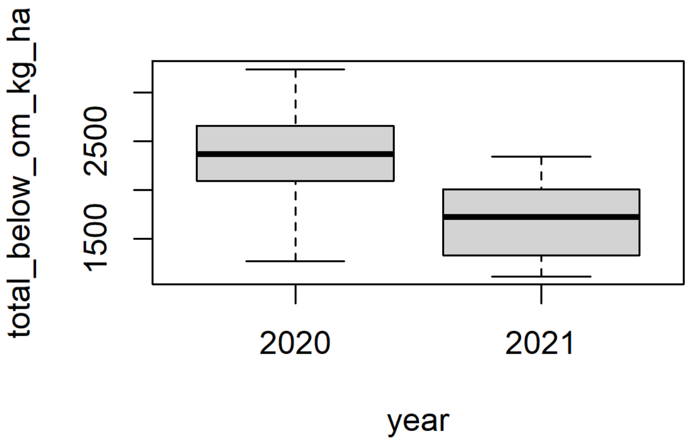
```
year             1 3516290 3516290 30.3298 4.777e-05 ***
cultivar_variety  2  199428   99714  0.8601    0.4418
Residuals        16 1854964  115935
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   1137 79.6 16      968     1306

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```



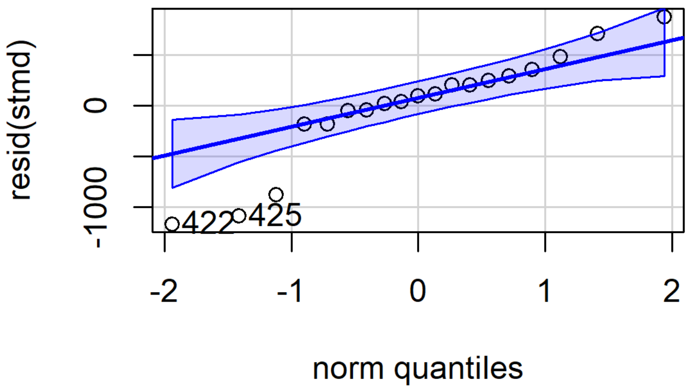

```
422 423
  2   3

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.11989, p-value = 0.9037
alternative hypothesis: two-sided
```

Belowground





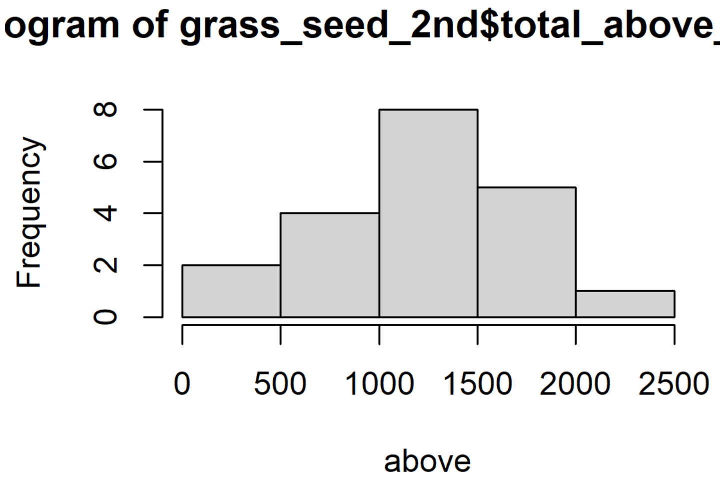

```
Analysis of Variance Table

Response: total_below_om_kg_ha
                Df   Sum Sq  Mean Sq F value    Pr(>F)
year             1 23436974 23436974 66.8690 6.566e-07 ***
cultivar_variety  2  1534692   767346  2.1893    0.1465
Residuals        15  5257363   350491
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   2727 140 15     2429     3025

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```



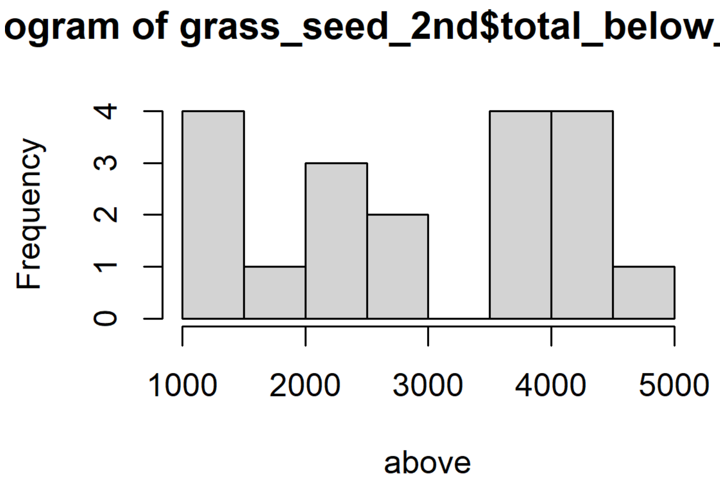

```
422 425
  2   5

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.20872, p-value = 0.332
alternative hypothesis: two-sided
```

Summary and statistical testing

```
# Aboveground
sum(!is.na(grass_seed_2nd$total_above_om_kg_ha))
 20
## IQR
summary(grass_seed_2nd$total_above_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
  429.8   705.3  1270.3  1231.6  1589.8  2481.9 
# Belowground
sum(!is.na(grass_seed_2nd$total_below_om_kg_ha))
 19
## IQR
summary(grass_seed_2nd$total_below_om_kg_ha, na.rm=TRUE)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's 
   1084    1907    2871    2934    4035    4908       1 
# Statistical testing

## Aboveground

	Shapiro-Wilk normality test

data:  grass_seed_2nd$total_above_om_kg_ha
W = 0.9562, p-value = 0.4709
```




```
One Sample t-test

data:  log(grass_seed_2nd$total_above_om_kg_ha)
t = -6.7212, df = 19, p-value = 2.009e-06
alternative hypothesis: true mean is not equal to 7.762171
95 percent confidence interval:
 6.773568 7.243077
sample estimates:
mean of x
 7.008322
## Belowground

   Shapiro-Wilk normality test

data:  grass_seed_2nd$total_below_om_kg_ha
W = 0.89584, p-value = 0.04094
```



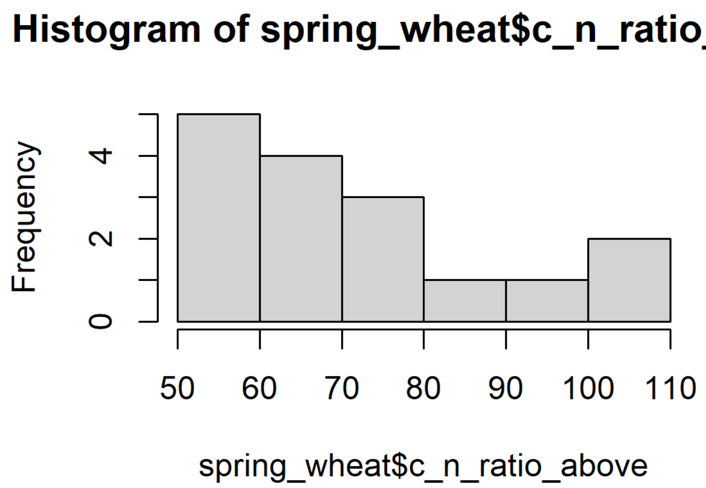

```
# No normal distribution

wilcox.test(grass_seed_2nd$total_below_om_kg_ha, mu = 4800, alternative = "two.sided")

   Wilcoxon signed rank exact test
```

```
data:  grass_seed_2nd$total_below_om_kg_ha
V = 1, p-value = 7.629e-06
alternative hypothesis: true location is not equal to 4800
```

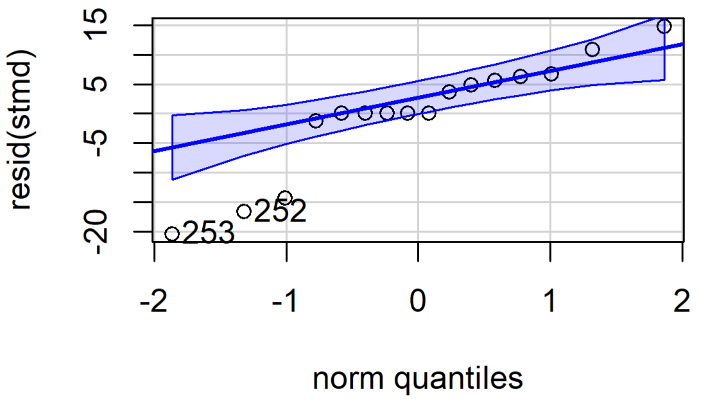
Appendix 3: C:N ratio

6.18 Spring wheat

Stubble



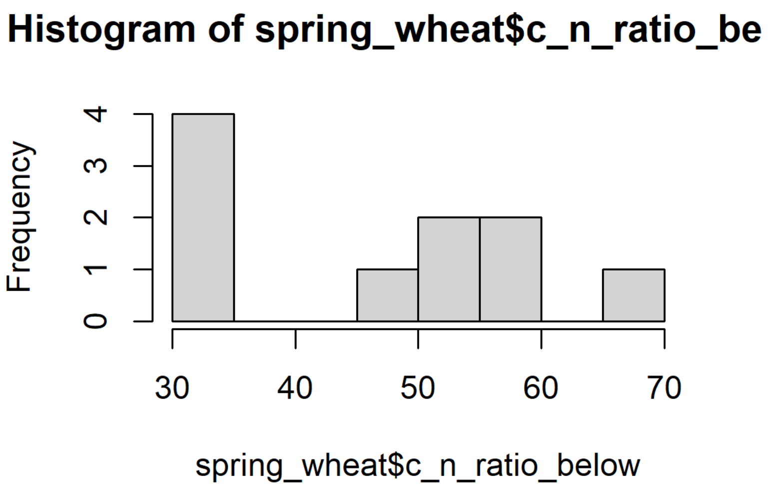

```
Analysis of Variance Table

Response: c_n_ratio_above
                Df  Sum Sq Mean Sq F value   Pr(>F)
year             1 1627.93 1627.93 12.9084 0.004223 **
soil_type        1 1581.18 1581.18 12.5378 0.004626 **
cultivar_variety  2  269.05  134.53  1.0667 0.377210
Residuals       11 1387.25  126.11
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   75.9 4.29 11     66.4     85.3

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```




```
253 252
 5   4

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.88738, p-value = 0.05063
```

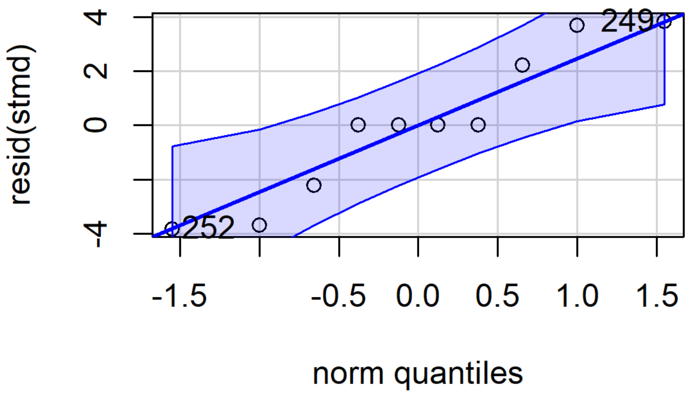
Model residues not normally distributed.

Belowground



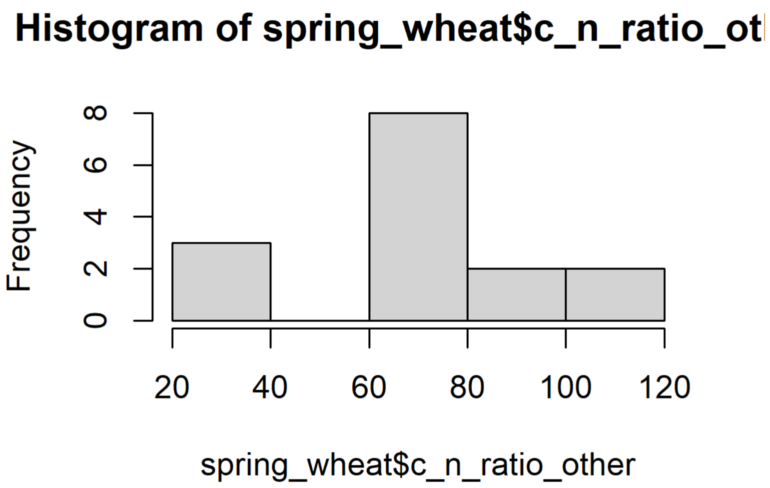

```
Analysis of Variance Table

Response: c_n_ratio_below
                 Df  Sum Sq Mean Sq F value    Pr(>F)
soil_type         1 1154.59 1154.59 104.147 5.158e-05 ***
cultivar_variety  2  146.03   73.01   6.586   0.03065 *
Residuals         6   66.52   11.09
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
1       emmean   SE df lower.CL upper.CL
overall   46.3 1.44  6     42.8     49.9

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```



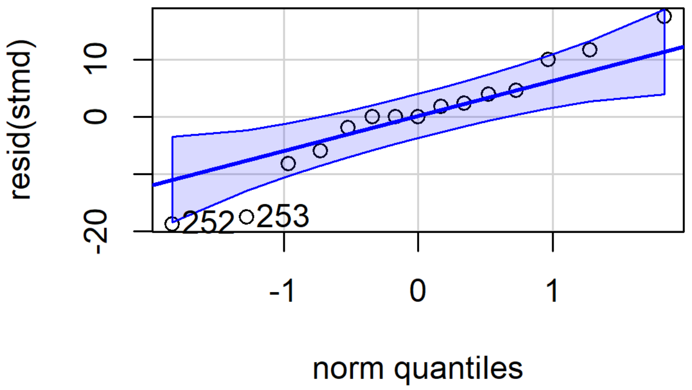

```
252 249
  4   1

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.90975, p-value = 0.2793
```

Straw



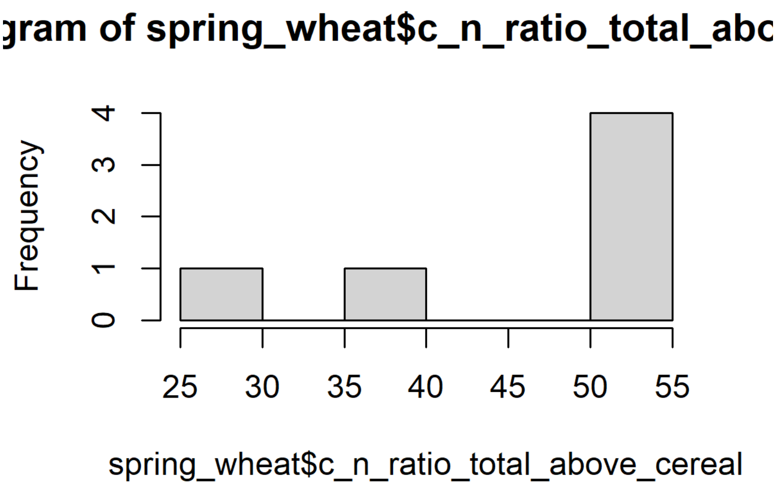

```
Analysis of Variance Table

Response: c_n_ratio_other
              Df Sum Sq Mean Sq F value    Pr(>F)
year           1 6844.0  6844.0 50.4699 3.279e-05 ***
soil_type      1 1417.2  1417.2 10.4512  0.008978 **
```

```
cultivar_variety  2  134.1    67.1  0.4946  0.623974
Residuals        10 1356.0   135.6
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   60.1 4.75 10     49.5     70.7

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



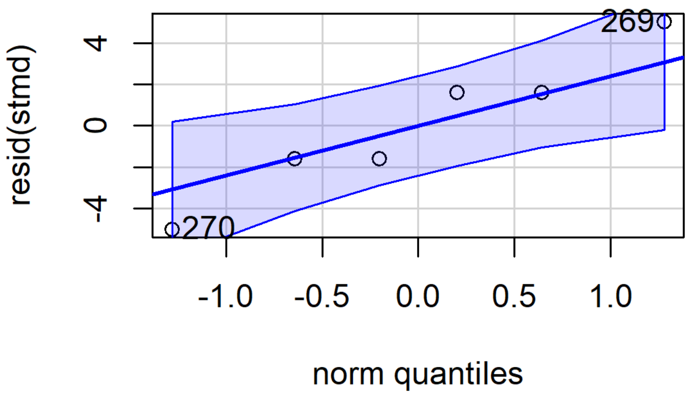

```
252 253
  4   5

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.95343, p-value = 0.5799
```

Stubble + Straw




```
Analysis of Variance Table
```

```
Response: c_n_ratio_total_above_cereal
                Df Sum Sq Mean Sq F value   Pr(>F)
cultivar_variety  1 579.83  579.83   38.17 0.003487 **
Residuals        4  60.76   15.19
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   42.5 1.69  4     37.8     47.2

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```




```
270 269
  6   5

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.96135, p-value = 0.8301
```

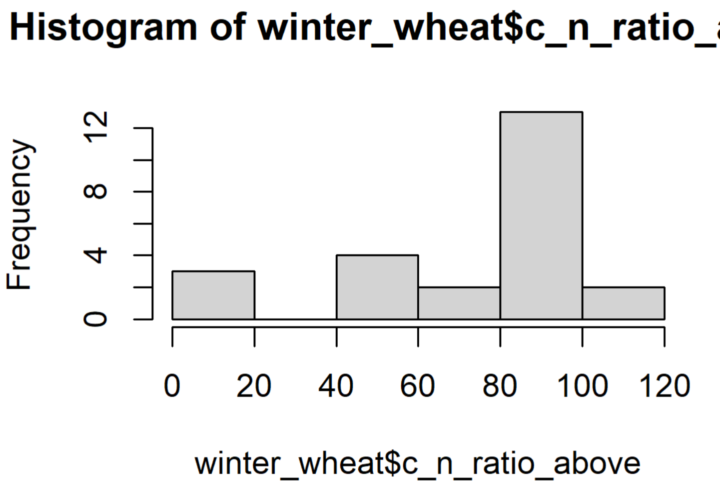
Summary

```
#Stubble
## Number of observations
sum(!is.na(spring_wheat$c_n_ratio_above))
 16
## Mean
weighted.mean(spring_wheat$c_n_ratio_above, spring_wheat$weights_above, na.rm=TRUE)
 72.64224
## Median
weighted.median(spring_wheat$c_n_ratio_above, spring_wheat$weights_above, na.rm=TRUE)
 66.65625
# Roots
## Number of observations
sum(!is.na(spring_wheat$c_n_ratio_below))
 10
# Straw
## Number of observations
sum(!is.na(spring_wheat$c_n_ratio_other))
 15
# Stubble + straw
## Number of observations
sum(!is.na(spring_wheat$c_n_ratio_total_above_cereal))
```

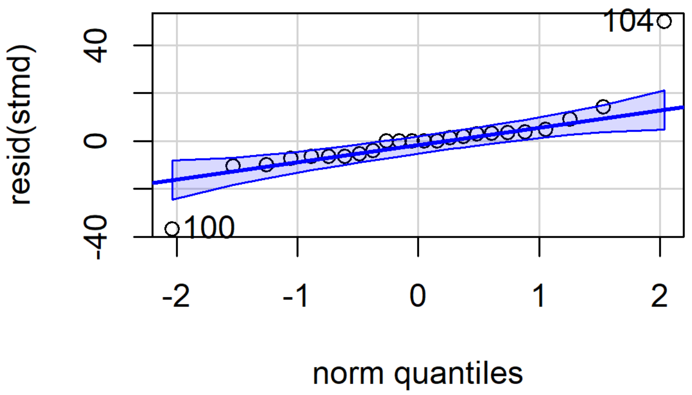
```
6
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(mean(EMM_stubble, EMM_straw), EMM_stubblestraw)
weight <- c(min(sum(!is.na(spring_wheat$c_n_ratio_above)), sum(!is.na(spring_wheat$c_n_ratio_other))), sum(!is.na(spring_whe
at$c_n_ratio_total_above_cereal)))
weighted.mean(values, weight, na.rm=TRUE)
 66.33079
```

6.19 Winter wheat

Stubble

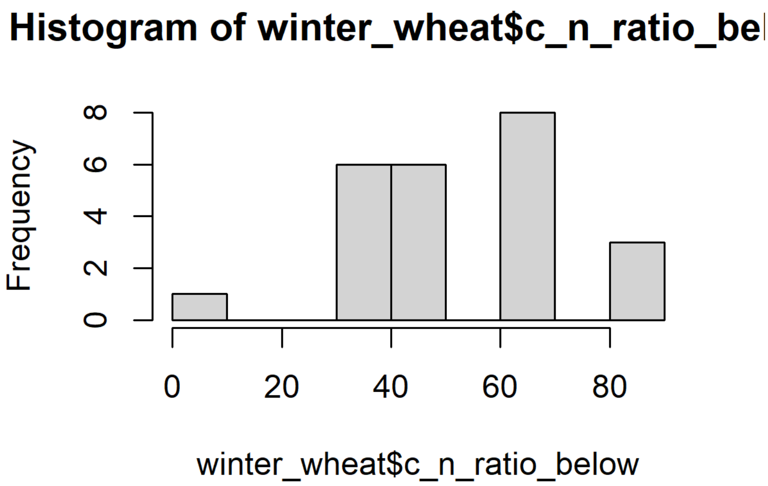



```
Analysis of Variance Table

Response: c_n_ratio_above
                   Df Sum Sq Mean Sq F value    Pr(>F)
year                1 3033.3  3033.3 11.1868 0.0038410 **
soil_type           1 8817.0  8817.0 32.5172 2.593e-05 ***
cultivar_variety    3 7219.0  2406.3  8.8747 0.0009194 ***
soil_type:location  1  450.2   450.2  1.6604 0.2148071
Residuals          17 4609.5   271.1
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall     68 6.88 17     53.5     82.5

Results are averaged over the levels of: year, cultivar_variety, location, soil_type
Confidence level used: 0.95
```



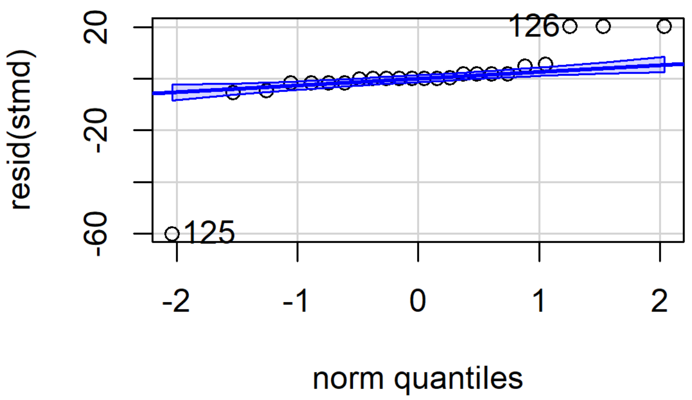

```
104 100
 14  10

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.24458, p-value = 0.1132
alternative hypothesis: two-sided
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
                 Df Sum Sq Mean Sq F value  Pr(>F)
soil_type         2 2910.7 1455.37  5.0015 0.01958 *
cultivar_variety  4  191.9   47.98  0.1649 0.95330
Residuals        17 4946.8  290.99
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   48.3 4.65 17     38.5     58.1
```

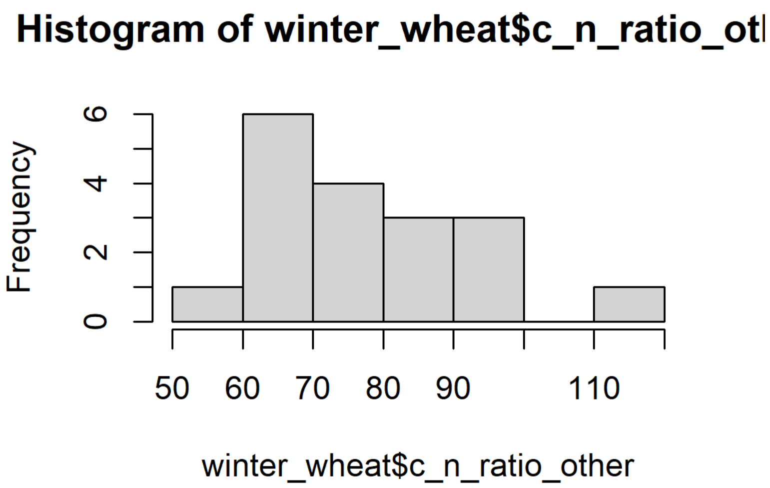
```
Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```




```
125 126
 17  18

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.32661, p-value = 0.01195
alternative hypothesis: two-sided
```

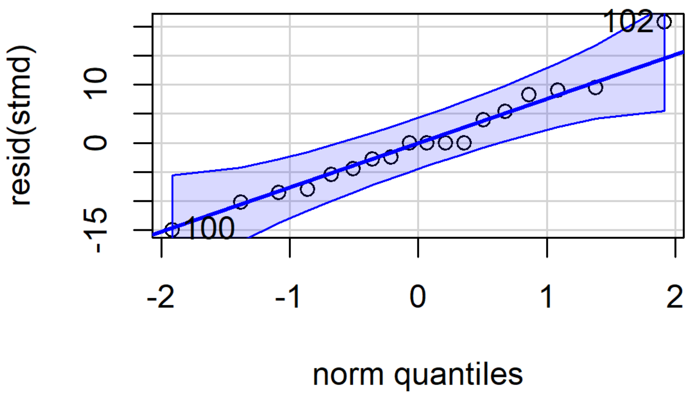
Residuals not normally distributed.

Straw



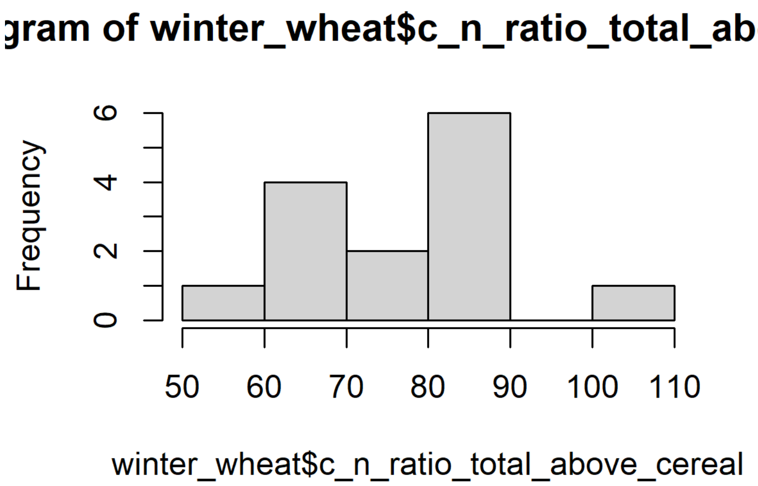

```
Analysis of Variance Table

Response: c_n_ratio_other
           Df  Sum Sq Mean Sq F value    Pr(>F)
year        1  511.29  511.29  4.9514 0.0460087 *
```

```
soil_type        1 1945.29 1945.29 18.8383 0.0009611 ***
cultivar_variety  3  175.21   58.40  0.5656 0.6480536
Residuals       12 1239.15  103.26
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall     66 4.4 12     56.5     75.6

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```

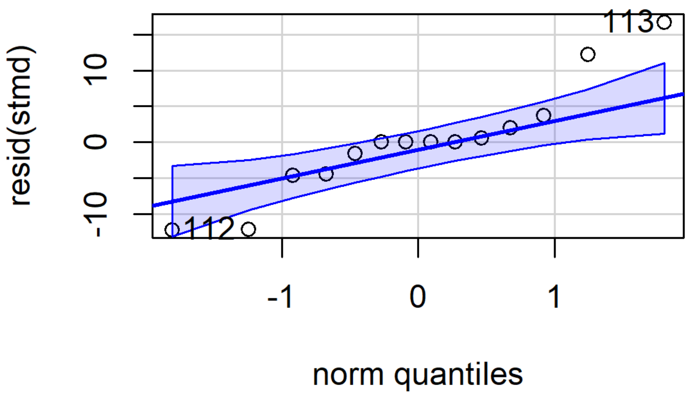



```
102 100
 12  10

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.96892, p-value = 0.7771
```

Stubble + Straw



```
Analysis of Variance Table

Response: c_n_ratio_total_above_cereal
              Df  Sum Sq Mean Sq F value    Pr(>F)
soil_type        1  287.43  287.43  4.0178 0.0702677 .
cultivar_variety  1 1449.20 1449.20 20.2570 0.0009001 ***
Residuals       11  786.95   71.54
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   63.5 3.66 11     55.5     71.6

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```




```
113 112
  3   2

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.90984, p-value = 0.1568
```

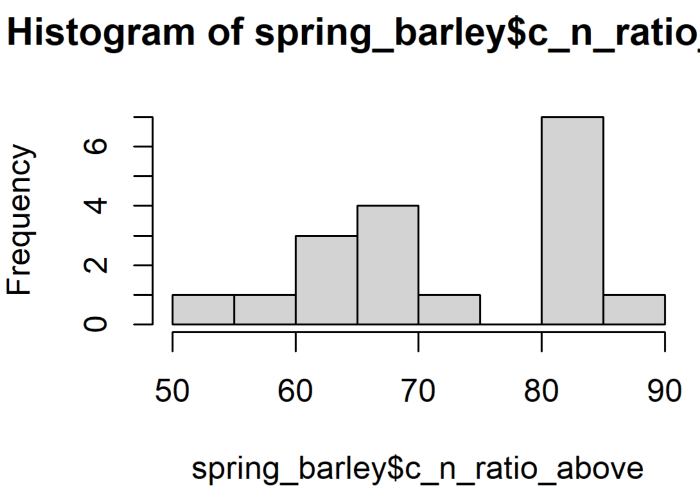
Summary

```
# Stubble
## Number of observations
sum(!is.na(winter_wheat$c_n_ratio_above))
 24
# Roots
## Number of observations
sum(!is.na(winter_wheat$c_n_ratio_below))
 24
mean(winter_wheat$c_n_ratio_below, na.rm=TRUE)
 52.73164
# Straw
## Number of observations
sum(!is.na(winter_wheat$c_n_ratio_other))
 18
# Stubble + straw
## Number of observations
sum(!is.na(winter_wheat$c_n_ratio_total_above_cereal))
 14
```

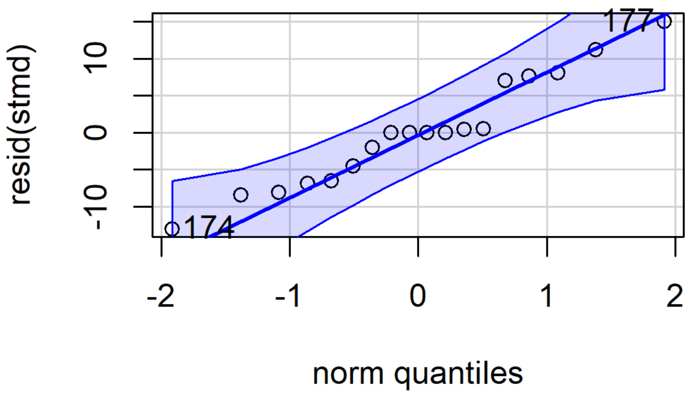
```
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(mean(EMM_stubble, EMM_straw), EMM_stubblestraw)
weight <- c(min(sum(!is.na(winter_wheat$c_n_ratio_above)), sum(!is.na(winter_wheat$c_n_ratio_other))), sum(!is.na(winter_wheat$c_n_ratio_total_above_cereal)))
weighted.mean(values, weight, na.rm=TRUE)
 66.0384
```

6.20 Spring barley

Stubble

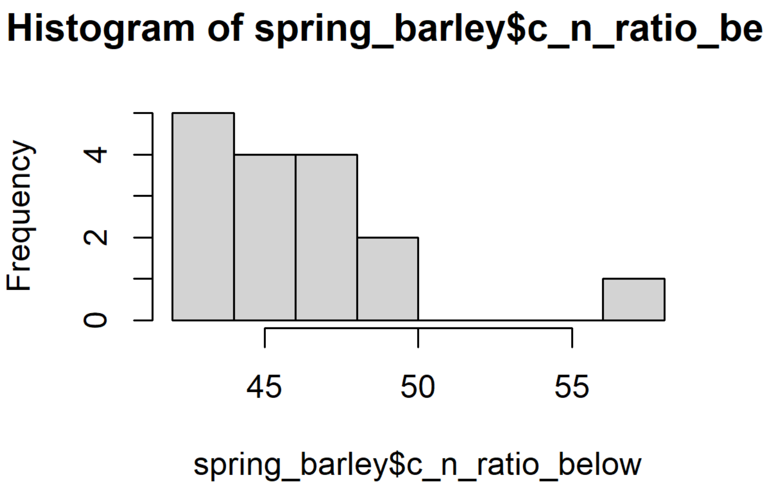



```
Analysis of Variance Table

Response: c_n_ratio_above
             Df Sum Sq Mean Sq F value  Pr(>F)
year          1 396.40  396.40  5.4491 0.03627 *
soil_type     1 564.80  564.80  7.7639 0.01543 *
cultivar_variety  2  20.49   10.25  0.1408 0.86993
Residuals    13 945.71   72.75
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   70.9 3.16 13     64.1     77.7

Results are averaged over the levels of: soil_type, cultivar_variety, year
Confidence level used: 0.95
```



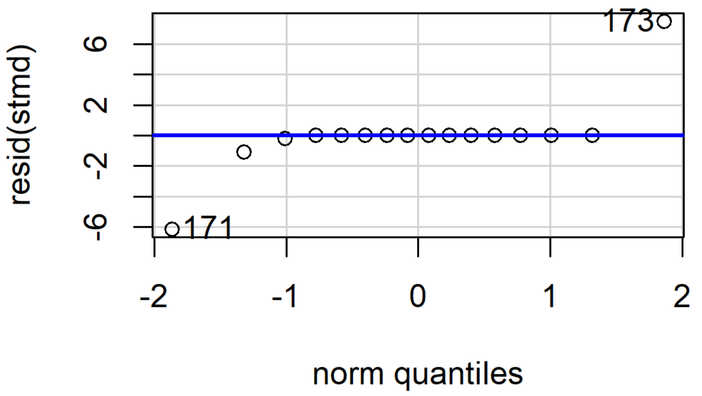

```
177 174
  8   5

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.95911, p-value = 0.5845
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
          Df Sum Sq Mean Sq F value Pr(>F)
year       1 23.450 23.4497  2.9781 0.1100
soil_type  2 46.580 23.2900  2.9579 0.0903 .
Residuals 12 94.487  7.8739
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   47.1 0.739 12     45.5     48.7
```

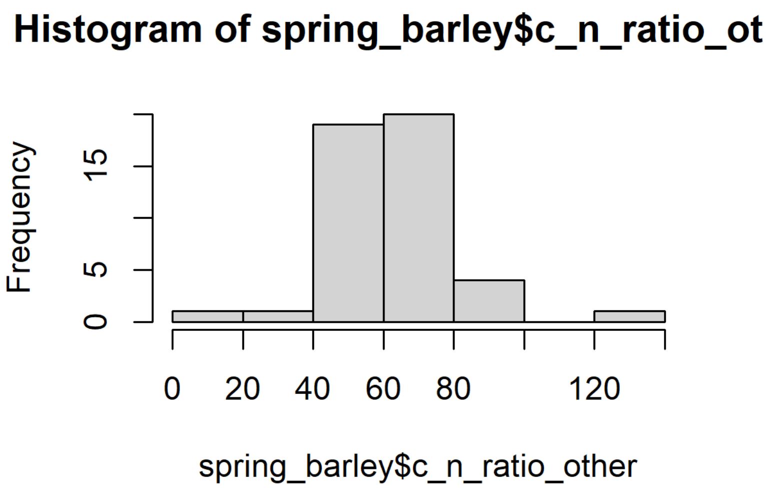
```
Results are averaged over the levels of: year, soil_type
Confidence level used: 0.95
```




```
173 171
  4   2

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.56206, p-value = 7.253e-06
```

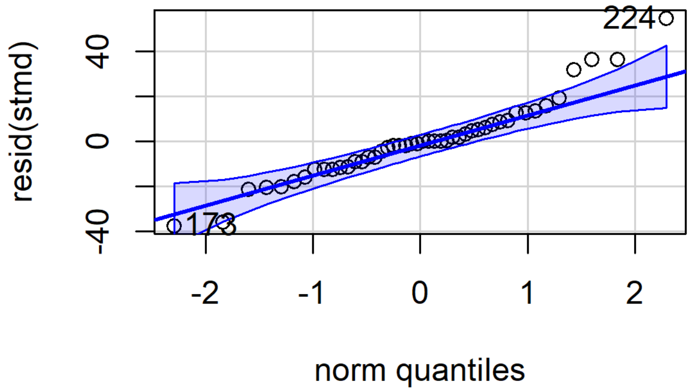
Residuals not normally distributed.

Straw



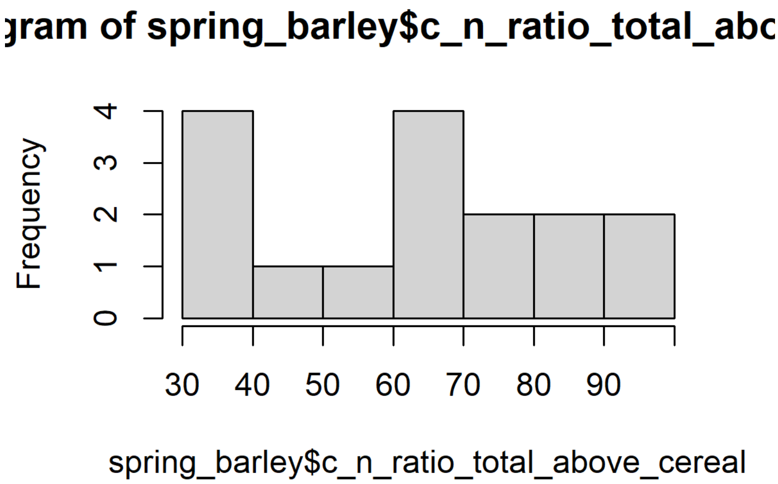

```
Analysis of Variance Table

Response: c_n_ratio_other
                Df  Sum Sq Mean Sq F value  Pr(>F)
soil_type        2  1897.0  948.49  2.7000 0.07976 .
cultivar_variety  4  1617.9  404.48  1.1514 0.34701
Residuals       39 13700.2  351.29
```

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   57.5 4.33 39     48.7     66.3

Results are averaged over the levels of: soil_type, cultivar_variety
Confidence level used: 0.95
```



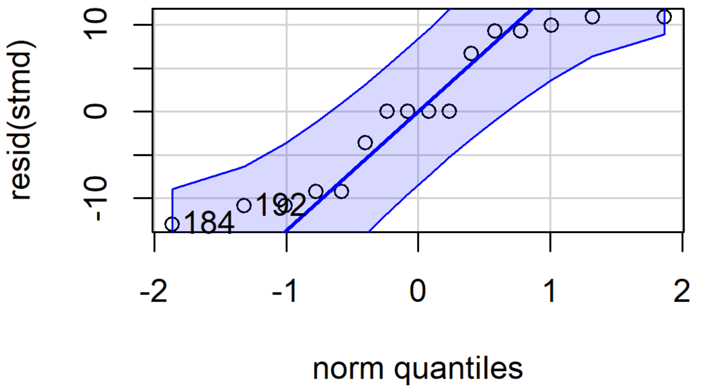

```
224 173
 33   4

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.1136, p-value = 0.5929
alternative hypothesis: two-sided
```

Stubble + Straw




```
Analysis of Variance Table

Response: c_n_ratio_total_above_cereal
```

```
                Df Sum Sq Mean Sq F value   Pr(>F)
year             1  237.1   237.1  2.4904   0.1405
soil_type        1 5199.4  5199.4 54.6089 8.39e-06 ***
cultivar_variety 1   67.4    67.4  0.7076   0.4167
Residuals       12 1142.5    95.2
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   68.1 3.45 12     60.6     75.6

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```




```
184 192
  1   9

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.88478, p-value = 0.04609
```

Residuals not normally distributed.

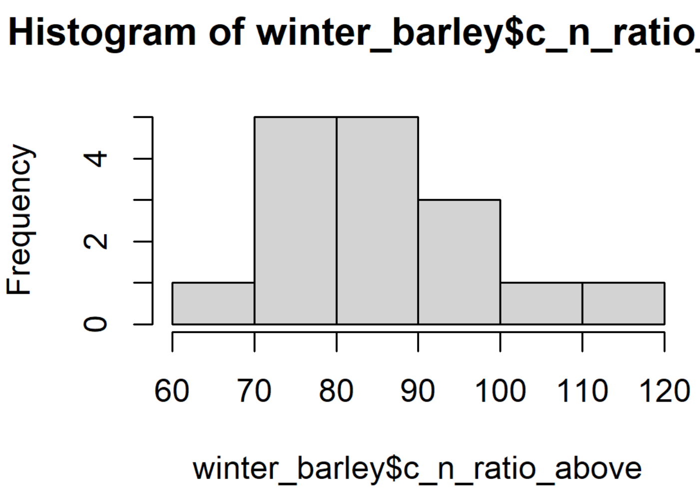
Summary

```
# Stubble
## Number of observations
sum(!is.na(spring_barley$c_n_ratio_above))
 18
# Roots
## Number of observations
sum(!is.na(spring_barley$c_n_ratio_below))
 16
## Mean
weighted.mean(spring_barley$c_n_ratio_below, spring_barley$weights_below, na.rm = TRUE)
 46.542
## Median
weighted.median(spring_barley$c_n_ratio_below, spring_barley$weights_below, na.rm = TRUE)
 45.84706
# Straw
## Number of observations
sum(!is.na(spring_barley$c_n_ratio_other))
 46
```

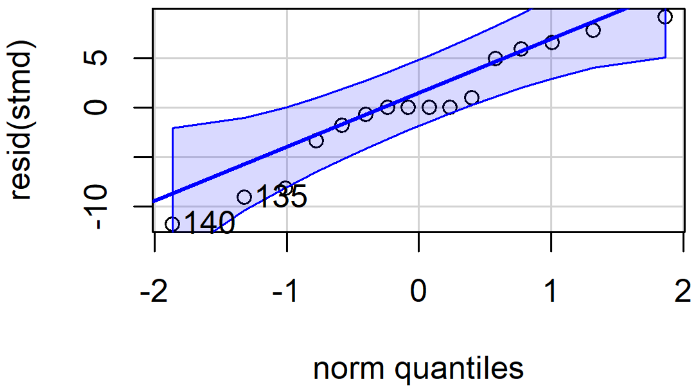
```
# Stubble + straw
## Number of observations
sum(!is.na(spring_barley$c_n_ratio_total_above_cereal))
 16
mean(spring_barley$c_n_ratio_total_above_cereal, na.rm=TRUE)
 64.41759
median(spring_barley$c_n_ratio_total_above_cereal, na.rm=TRUE)
 67.57031
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(mean(EMM_stubble, EMM_straw), EMM_stubblestraw)
weight <- c(min(sum(!is.na(spring_barley$c_n_ratio_above)), sum(!is.na(spring_barley$c_n_ratio_other))), sum(!is.na(spring_barle
y$c_n_ratio_total_above_cereal)))
weighted.mean(values, weight, na.rm=TRUE)
 69.59573
```

6.21 Winter barley

Stubble

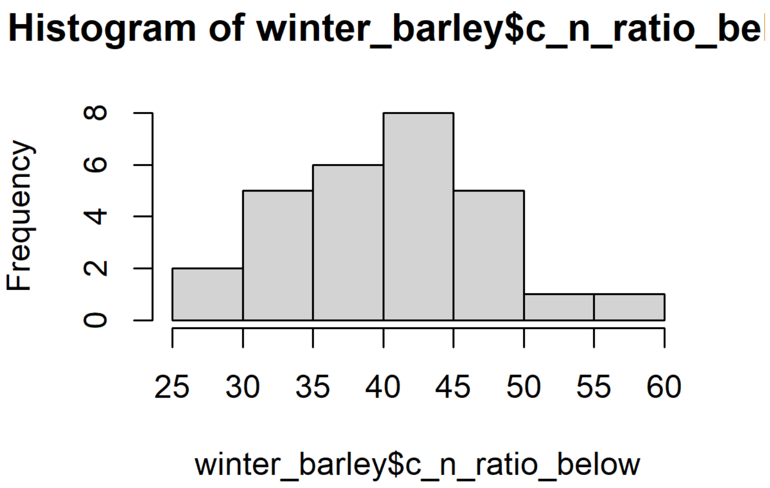



```
Analysis of Variance Table

Response: c_n_ratio_above
             Df  Sum Sq Mean Sq F value    Pr(>F)    
year          1    0.68    0.68  0.0135 0.9095844    
soil_type       1 1282.73 1282.73 25.6384 0.0003643 ***
cultivar_variety  2  410.96  205.48  4.1070 0.0465337 *  
Residuals        11  550.35   50.03                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean  SE df lower.CL upper.CL
 overall   82.1 2.5 11     76.6     87.6

Results are averaged over the levels of: year, soil_type, cultivar_variety 
Confidence level used: 0.95
```



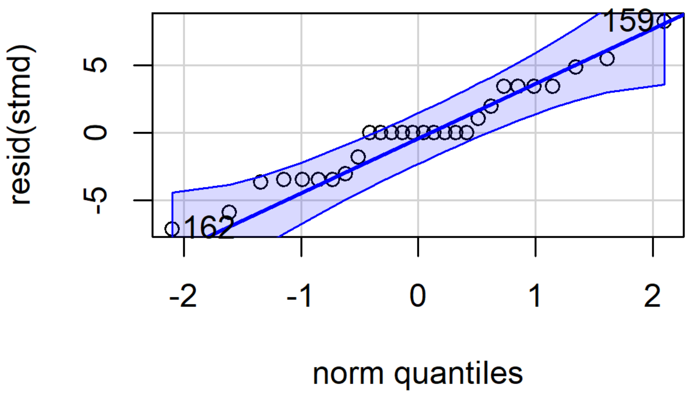

```
140 135
  6   1

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.94271, p-value = 0.3835
```

Belowground



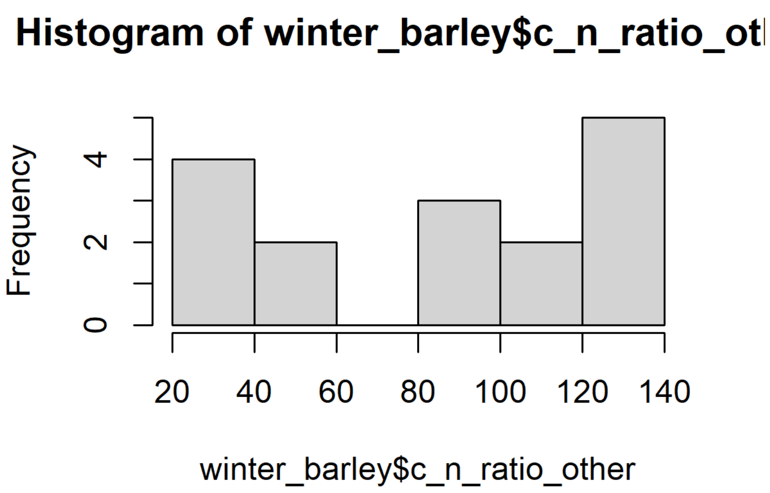

```
Analysis of Variance Table

Response: c_n_ratio_below
                   Df Sum Sq Mean Sq F value    Pr(>F)    
year                1 149.02  149.02  9.4497  0.005757 ** 
soil_type           2 231.03  115.52  7.3253  0.003860 ** 
cultivar_variety    2 236.99  118.50  7.5142  0.003456 ** 
soil_type:location  1 391.28  391.28 24.8124 6.266e-05 ***
Residuals          21 331.16   15.77                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
 1      emmean   SE df lower.CL upper.CL
 overall   39.1 1.18 21     36.6     41.5

Results are averaged over the levels of: year, cultivar_variety, location, soil_type
Confidence level used: 0.95
```



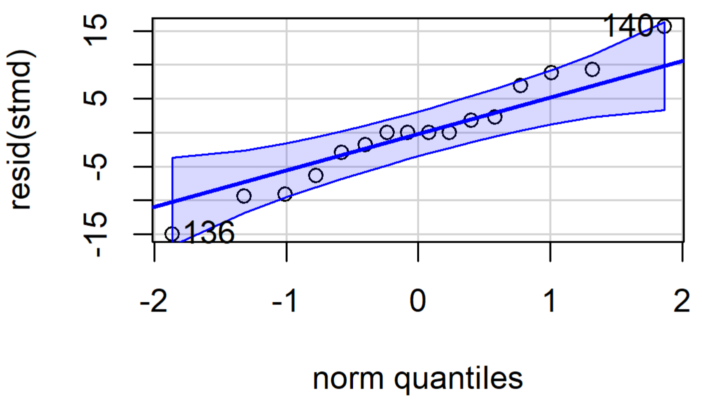

```
159 162
 19  22

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.17857, p-value = 0.3338
alternative hypothesis: two-sided
```

Straw



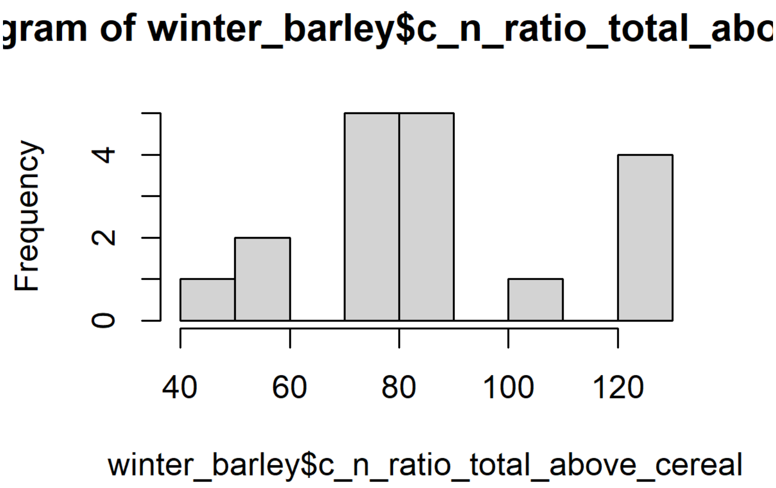

```
Analysis of Variance Table

Response: c_n_ratio_other
            Df  Sum Sq Mean Sq  F value    Pr(>F)
year         1  8769.8  8769.8 106.1318 5.487e-07 ***
```

```
soil_type        1 10931.2 10931.2 132.2897 1.797e-07 ***
cultivar_variety  2   963.2   481.6   5.8284    0.0188 *
Residuals        11   908.9    82.6
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   85.8 3.21 11     78.7     92.9

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```

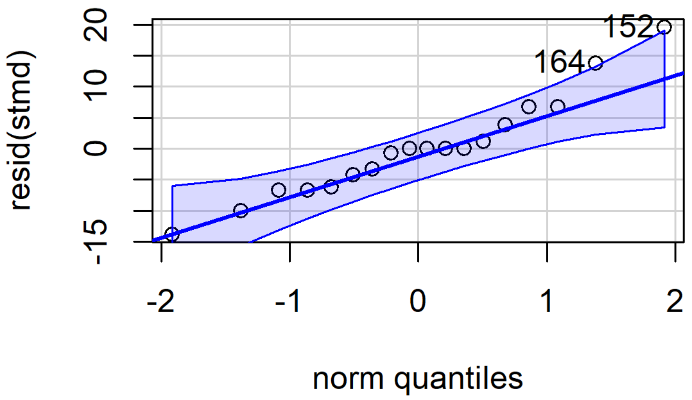



```
140 136
  6   2

    Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.97517, p-value = 0.9137
```

Stubble + Straw



```
Analysis of Variance Table

Response: c_n_ratio_total_above_cereal
          Df Sum Sq Mean Sq F value    Pr(>F)
year       1   92.2    92.2  1.1454    0.3026
soil_type  2 9618.4  4809.2 59.7752 1.391e-07 ***
Residuals 14 1126.4    80.5
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   58.2 3.36 14       51     65.4

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```




```
152 164
  6  18

	Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.95101, p-value = 0.441
```

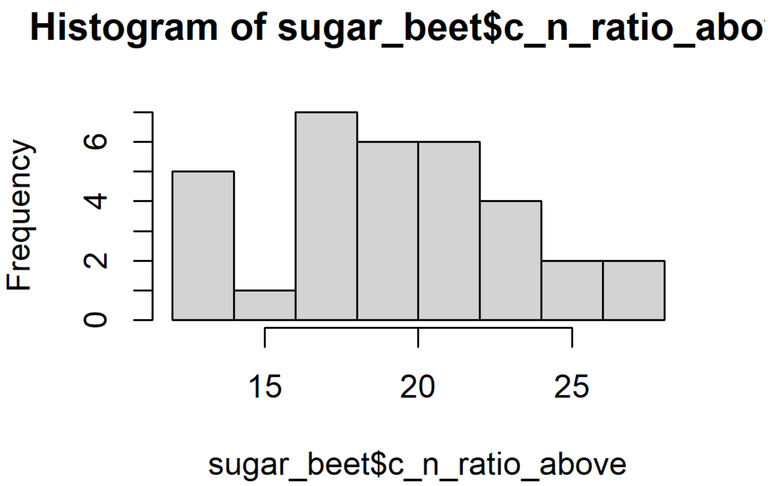
Summary

```
# Stubble
## Number of observations
sum(!is.na(winter_barley$c_n_ratio_above))
 16
# Roots
## Number of observations
sum(!is.na(winter_barley$c_n_ratio_below))
 28
# Straw
## Number of observations
sum(!is.na(winter_barley$c_n_ratio_other))
 16
# Stubble + straw
## Number of observations
sum(!is.na(winter_barley$c_n_ratio_total_above_cereal))
 18
# Weighted mean of EMM of measured and calculated stubble + straw
values <- c(mean(EMM_stubble, EMM_straw), EMM_stubblestraw)
```

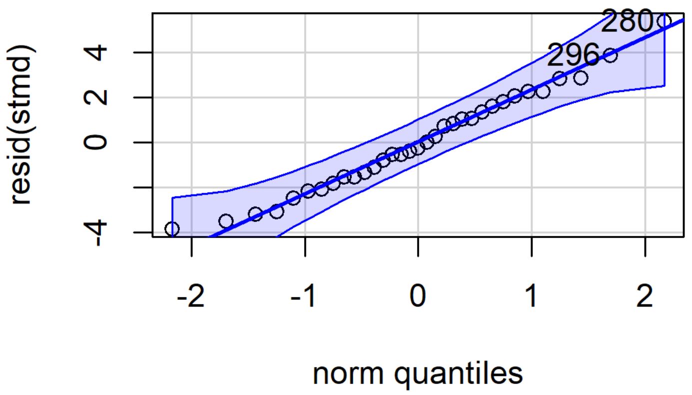
```
weight <- c(min(sum(!is.na(spring_wheat$c_n_ratio_above)), sum(!is.na(spring_wheat$c_n_ratio_other))), sum(!is.na(spring_wheat$c_n_ratio_total_above_cereal)))
weighted.mean(values, weight, na.rm=TRUE)
 75.2567
```

6.22 Sugar beet

Aboveground

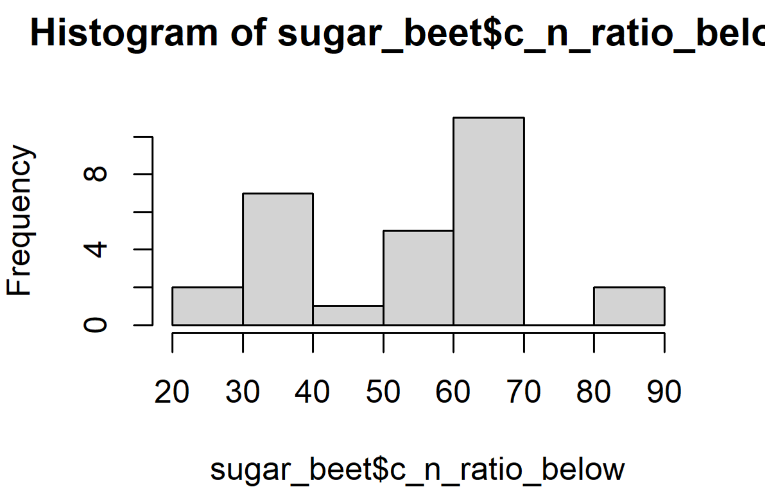



```
Analysis of Variance Table

Response: c_n_ratio_above
                Df  Sum Sq Mean Sq F value   Pr(>F)
year             1   4.158   4.158  0.6263 0.436468
cultivar_variety  7 296.329  42.333  6.3764 0.000266 ***
Residuals        24 159.334   6.639
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   19.5 0.569 24     18.3     20.7

Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```



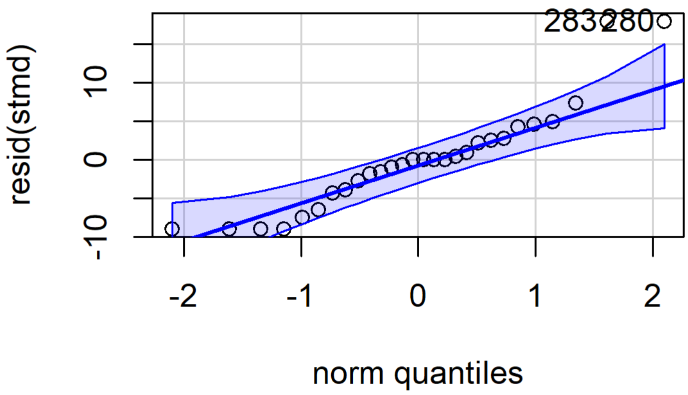

```
280 296
 9  25

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.060703, p-value = 0.9991
alternative hypothesis: two-sided
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
              Df Sum Sq Mean Sq F value    Pr(>F)
year             1 3266.6  3266.6 52.4100 5.263e-07 ***
soil_type        2 2158.2  1079.1 17.3133 4.328e-05 ***
cultivar_variety  4  855.5   213.9  3.4314   0.02727 *
Residuals       20 1246.5    62.3
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
 1       emmean   SE df lower.CL upper.CL
 overall     44 2.15 20     39.6     48.5

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



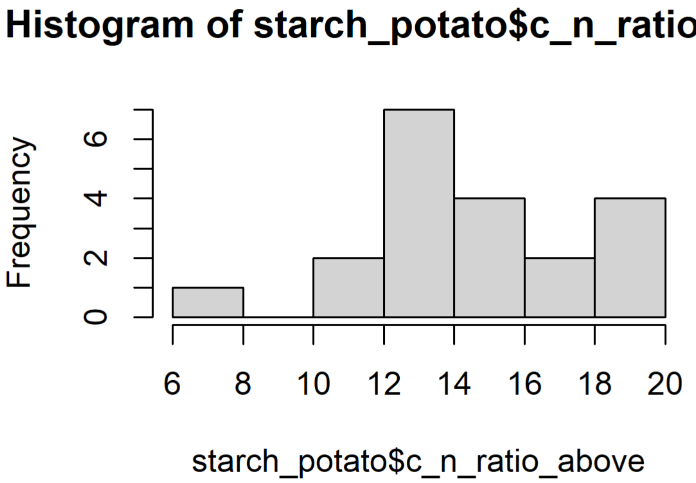

```
280 283
  9  10

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.12909, p-value = 0.7392
alternative hypothesis: two-sided
```

Summary

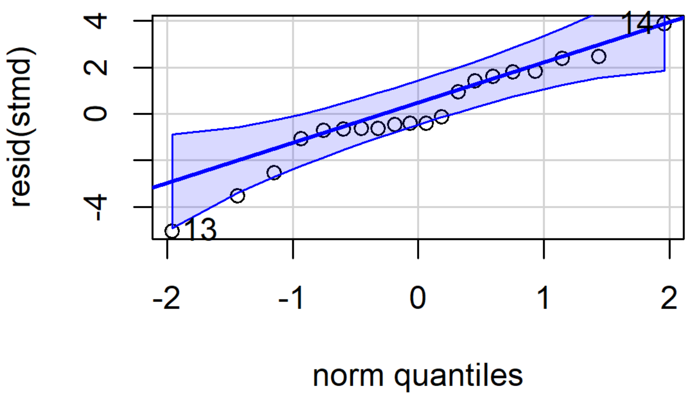
```
# Aboveground
sum(!is.na(sugar_beet$c_n_ratio_above))
 33
# Belowground
sum(!is.na(sugar_beet$c_n_ratio_below))
 28
```

6.23 Starch potato

Aboveground

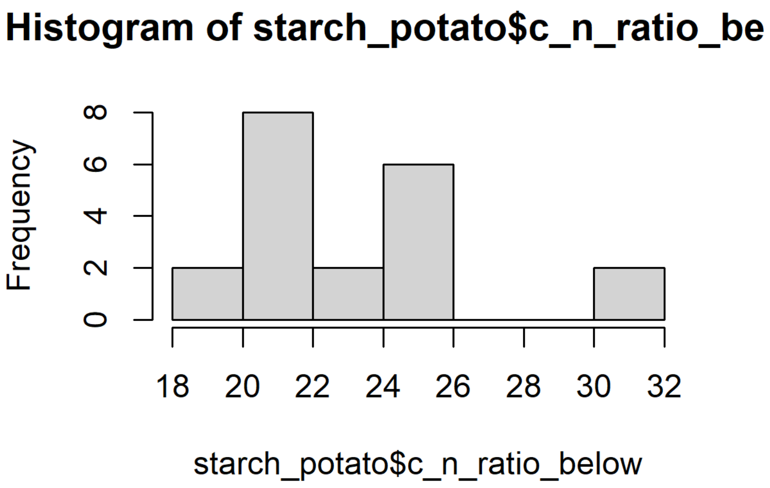



```
Analysis of Variance Table

Response: c_n_ratio_above
              Df  Sum Sq Mean Sq F value  Pr(>F)
cultivar_variety  4 100.841 25.2102  4.3741 0.01528 *
Residuals        15  86.453  5.7635
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   14.5 0.537 15     13.3     15.6

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```

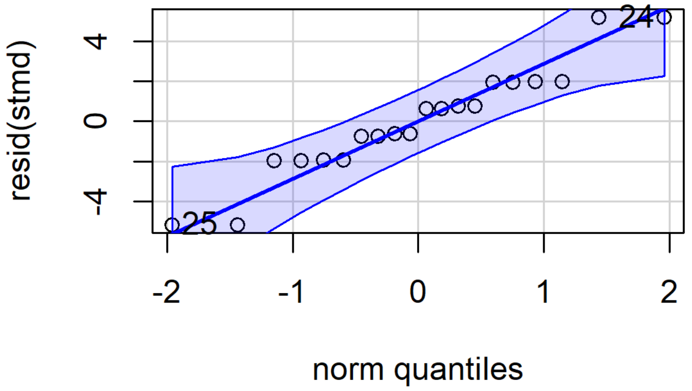



```
13 14
 3  4

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.16986, p-value = 0.5544
alternative hypothesis: two-sided
```

Belowground

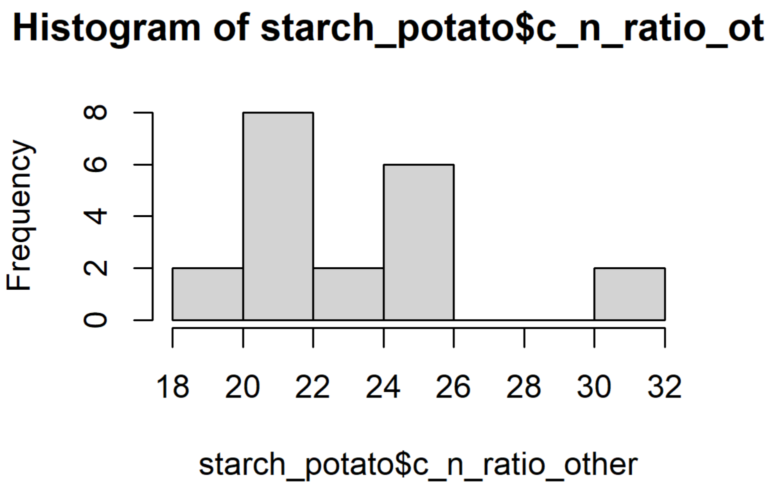



```
Analysis of Variance Table

Response: c_n_ratio_below
                Df  Sum Sq Mean Sq F value Pr(>F)
cultivar_variety  4  60.772 15.1931  1.6224 0.2202
Residuals        15 140.465  9.3643
 1       emmean    SE df lower.CL upper.CL
 overall   23.2 0.684 15     21.7     24.6

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```

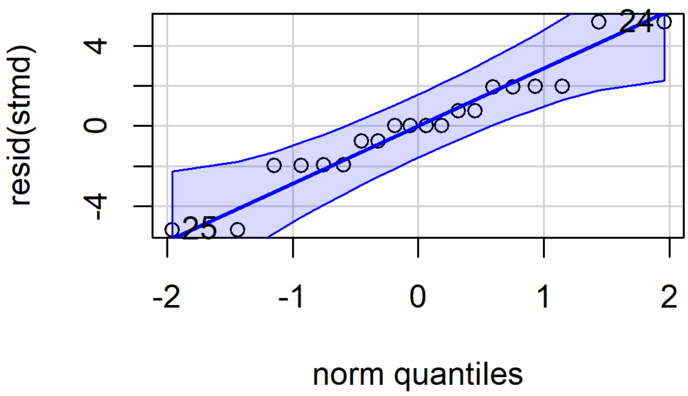



```
24 25
14 15

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.13632, p-value = 0.8513
alternative hypothesis: two-sided
```

Baby potatoes




```
Analysis of Variance Table

Response: c_n_ratio_other
              Df  Sum Sq Mean Sq F value Pr(>F)
cultivar_variety  4  49.481 12.3702  1.3365  0.302
Residuals       15 138.834  9.2556
 1       emmean   SE df lower.CL upper.CL
 overall   23.3 0.68 15     21.8     24.7

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```




```
24 25
14 15

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.13502, p-value = 0.8592
alternative hypothesis: two-sided
```

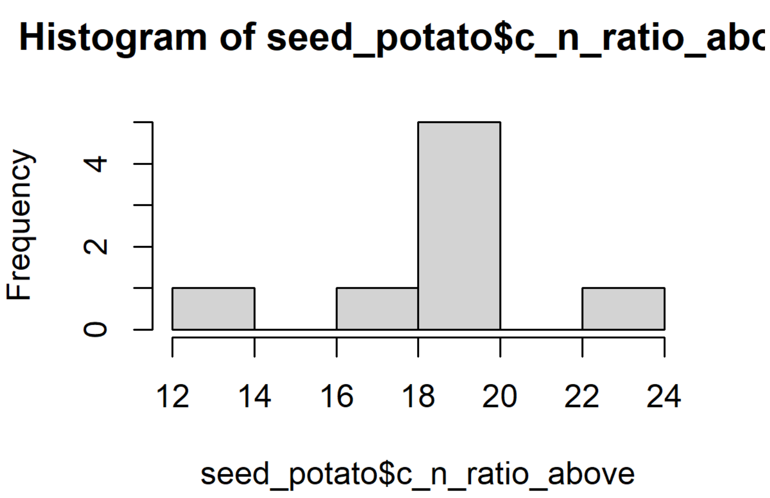
Summary

```
# Aboveground
## Number of observations
sum(!is.na(starch_potato$c_n_ratio_above))
 20
# Belowground
## Number of observations
sum(!is.na(starch_potato$c_n_ratio_below))
 20
# Baby potatoes
## Number of observations
sum(!is.na(starch_potato$c_n_ratio_other))
 20
```

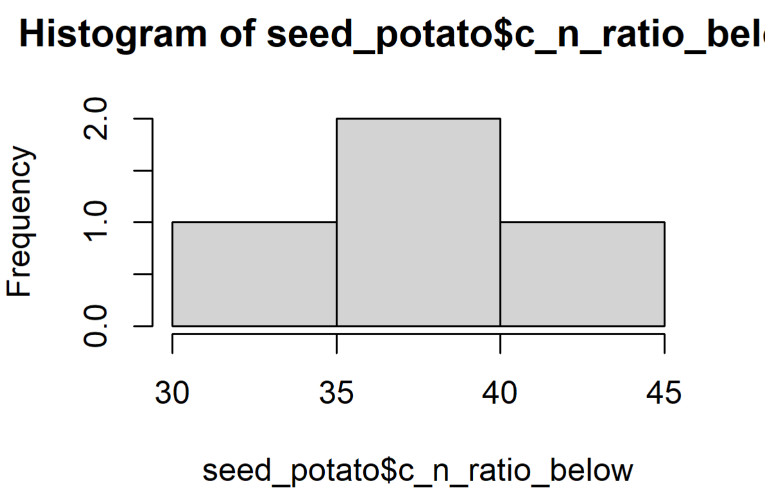
6.24 Seed potato

Summary

```
# Above
```



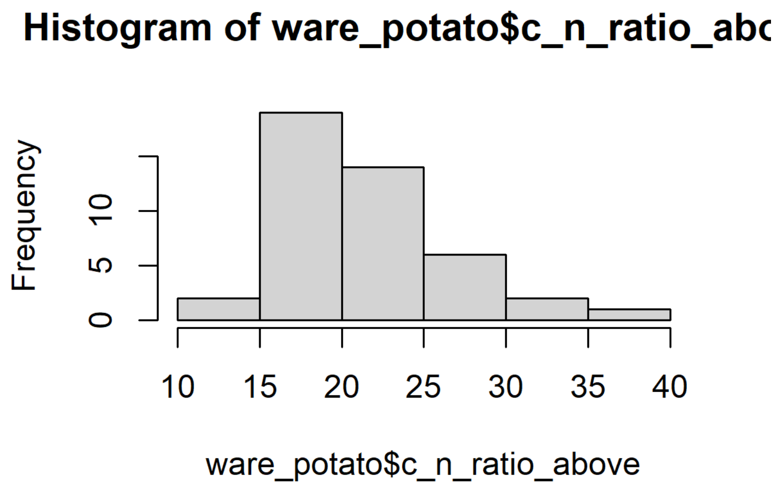

```
# Below
```



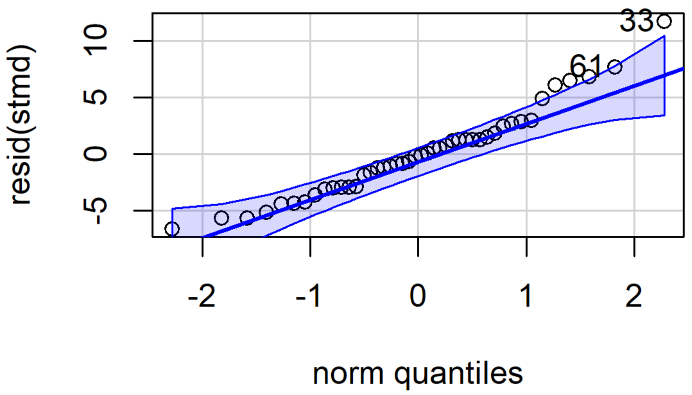
```
# Too little data to make modelling useful.

# Aboveground
## Number of observations
sum(!is.na(seed_potato$c_n_ratio_above))
 8
## Mean
weighted.mean(seed_potato$c_n_ratio_above, seed_potato$weights_above, na.rm = TRUE)
 18.02463
# Belowground
## Number of observations
sum(!is.na(seed_potato$c_n_ratio_below))
 4
## Mean
weighted.mean(seed_potato$c_n_ratio_below, seed_potato$weights_below, na.rm = TRUE)
 36.8174
# Baby potato
# No data
```

6.25 Ware potato

Aboveground

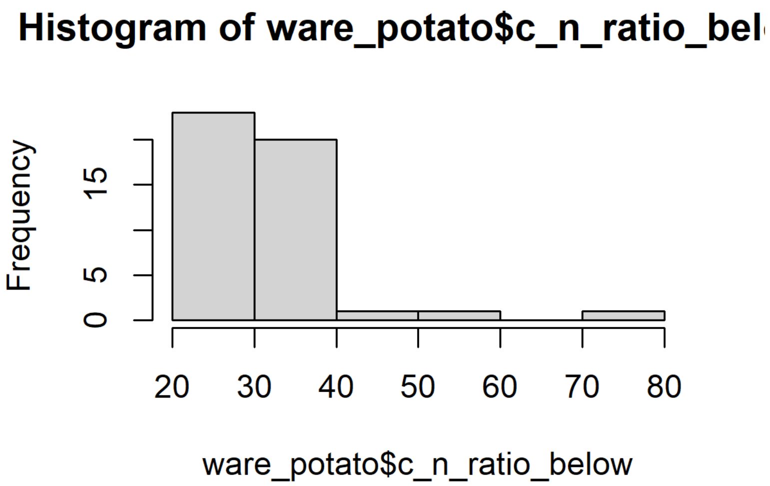



```
Analysis of Variance Table

Response: c_n_ratio_above
              Df Sum Sq Mean Sq F value   Pr(>F)
year           1   0.65   0.650  0.0350 0.852761
soil_type      1   1.08   1.076  0.0579 0.811323
cultivar_variety  6 464.73  77.454  4.1657 0.002919 **
Residuals     35 650.77  18.593
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   20.7 1.52 35     17.6     23.8

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



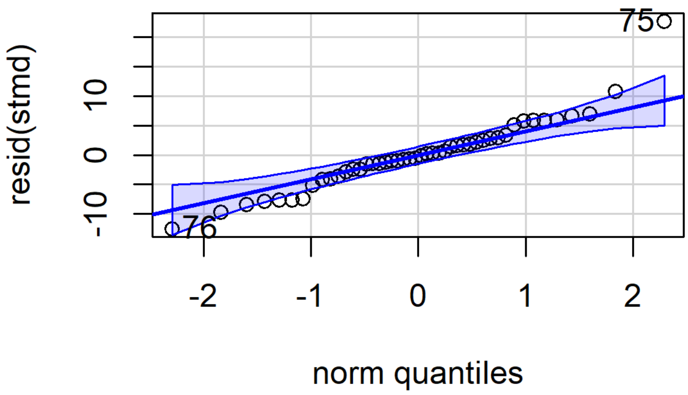

```
33 61
 2 30

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.10469, p-value = 0.7205
alternative hypothesis: two-sided
```

Belowground



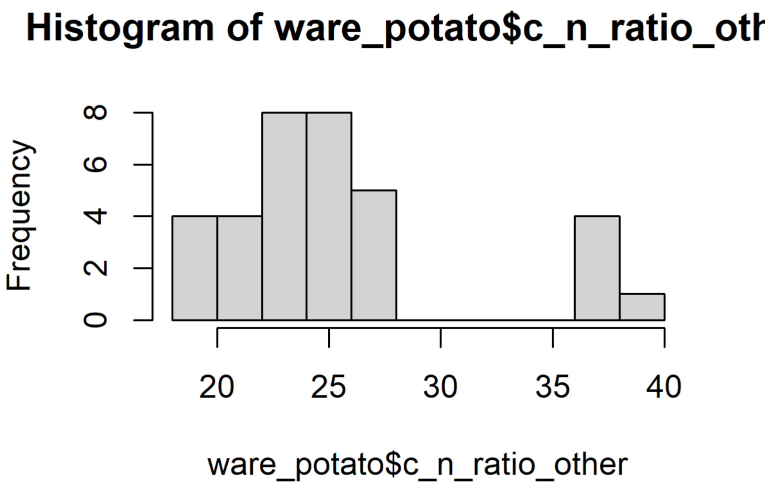

```
Analysis of Variance Table

Response: c_n_ratio_below
                Df  Sum Sq Mean Sq F value    Pr(>F)
year             1  639.27  639.27 14.8135 0.0004538 ***
soil_type        1   91.37   91.37  2.1172 0.1540882
cultivar_variety 6 1113.23  185.54  4.2994 0.0021951 **
Residuals       37 1596.72   43.15
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
 1      emmean   SE df lower.CL upper.CL
 overall   33.4 2.16 37      29     37.7

Results are averaged over the levels of: year, soil_type, cultivar_variety
Confidence level used: 0.95
```



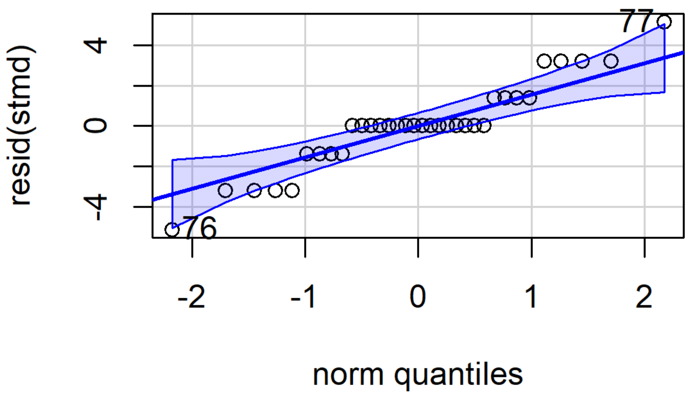

```
75 76
44 45

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.096762, p-value = 0.7459
alternative hypothesis: two-sided
```

Baby potatoes




```
Analysis of Variance Table

Response: c_n_ratio_other
             Df Sum Sq Mean Sq F value    Pr(>F)
cultivar_variety  6 939.65  156.61  28.065 2.125e-10 ***
```

```
Residuals       27 150.66    5.58
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   26.8 0.446 27     25.9     27.7

Results are averaged over the levels of: cultivar_variety
Confidence level used: 0.95
```




```
76 77
33 34

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.23529, p-value = 0.04635
alternative hypothesis: two-sided
```

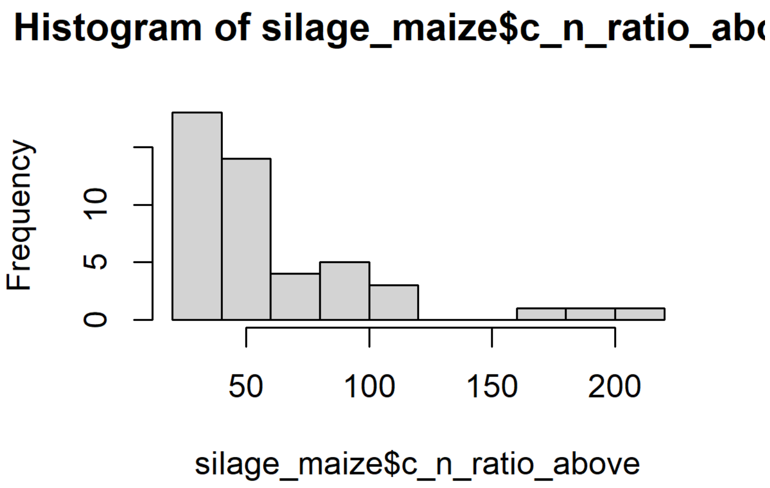
Residuals are not normally distributed.

Summary

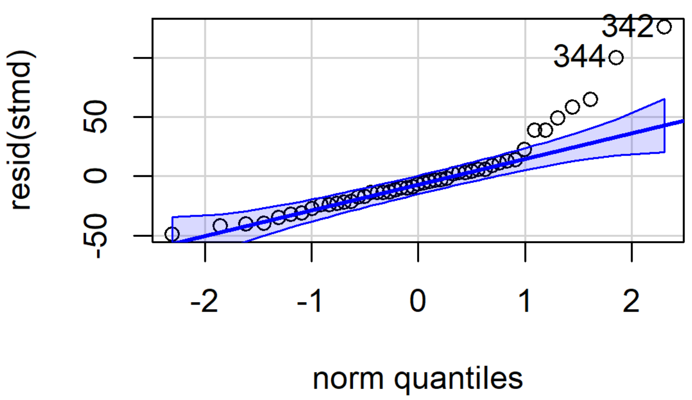
```
# Aboveground
## Number of observations
sum(!is.na(ware_potato$c_n_ratio_above))
 44
# Belowground
## Number of observations
sum(!is.na(ware_potato$c_n_ratio_below))
 46
# Baby potatoes
## Number of observations
sum(!is.na(ware_potato$c_n_ratio_other))
 34
## Mean
weighted.mean(ware_potato$c_n_ratio_other, ware_potato$weights_below, na.rm = TRUE)
 25.5751
## Median
weighted.median(ware_potato$c_n_ratio_other, ware_potato$weights_below, na.rm = TRUE)
 25.23214
```

6.26 Silage maize

Aboveground



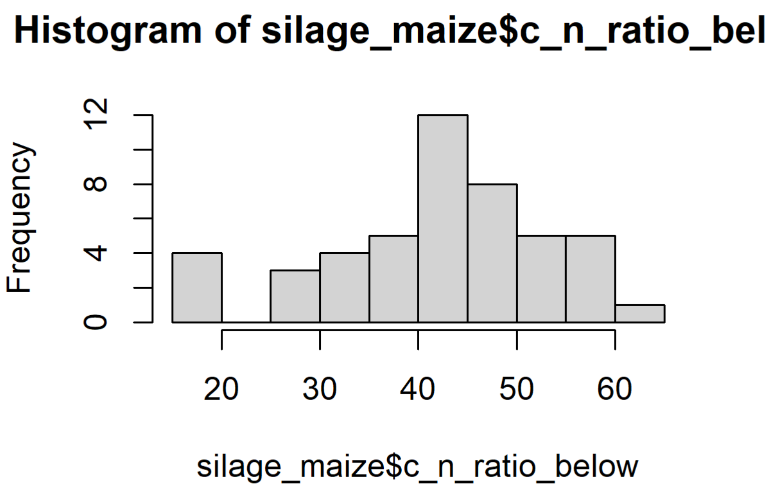

```
Analysis of Variance Table

Response: c_n_ratio_above
          Df Sum Sq Mean Sq F value    Pr(>F)
year       3  42064 14021.3  8.9591 0.0001048 ***
soil_type  1    277   277.3  0.1772 0.6759490
Residuals 42  65731  1565.0
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean SE df lower.CL upper.CL
 overall   92.5 12 42     68.4      117

Results are averaged over the levels of: year, soil_type
Confidence level used: 0.95
```



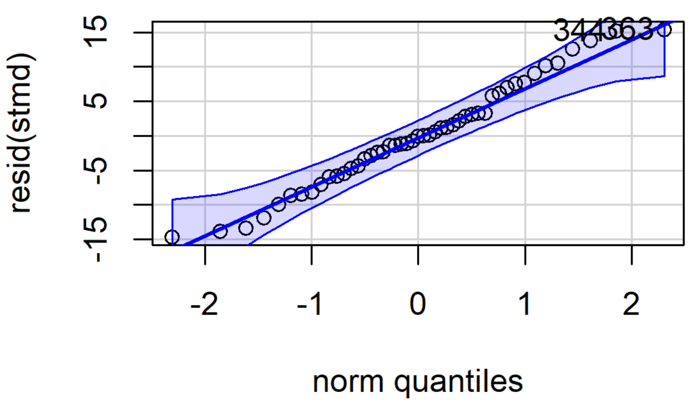

```
342 344
 16  18

	One-sample Kolmogorov-Smirnov test
```

```
data:  resid(stmd)
D = 0.17774, p-value = 0.09046
alternative hypothesis: two-sided
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
          Df Sum Sq Mean Sq F value    Pr(>F)
year       3 7305.6 2435.21 38.3371 4.274e-12 ***
soil_type  1  398.3  398.27  6.2698   0.01625 *
Residuals 42 2667.9   63.52
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   35.8 2.41 42     30.9     40.6

Results are averaged over the levels of: year, soil_type
Confidence level used: 0.95
```




```
363 344
 37  18
```

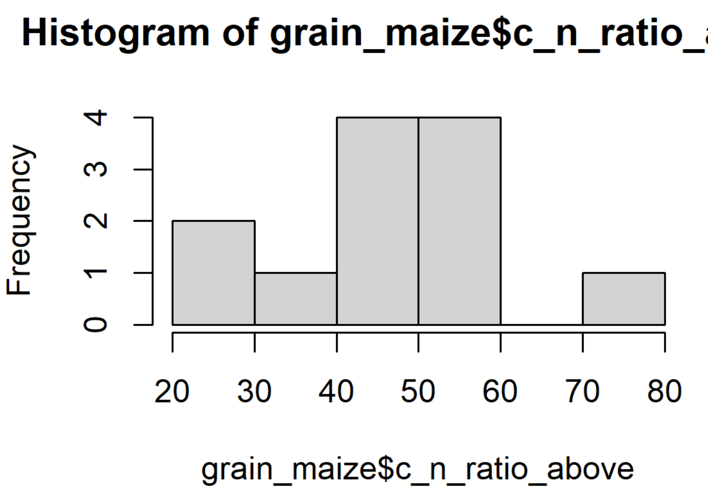
```
   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.080463, p-value = 0.8972
alternative hypothesis: two-sided
```

Summary

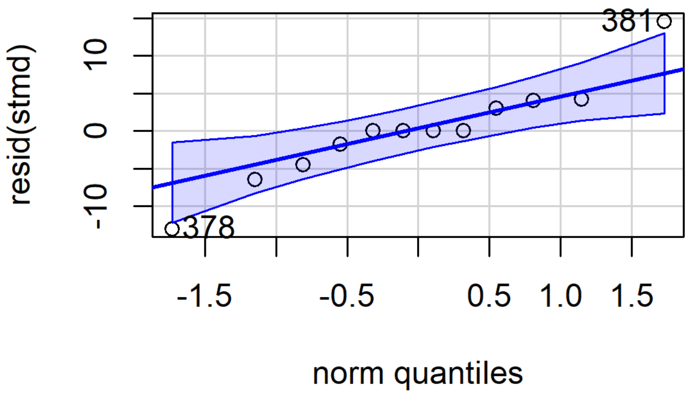
```
# Aboveground
## Number of observations
sum(!is.na(silage_maize$c_n_ratio_above))
 47
## Mean
weighted.mean(silage_maize$c_n_ratio_above , silage_maize$weights_above, na.rm = TRUE)
 68.95038
# Belowground
## Number of observations
sum(!is.na(silage_maize$c_n_ratio_below))
 47
```

6.27 Grain maize

Aboveground

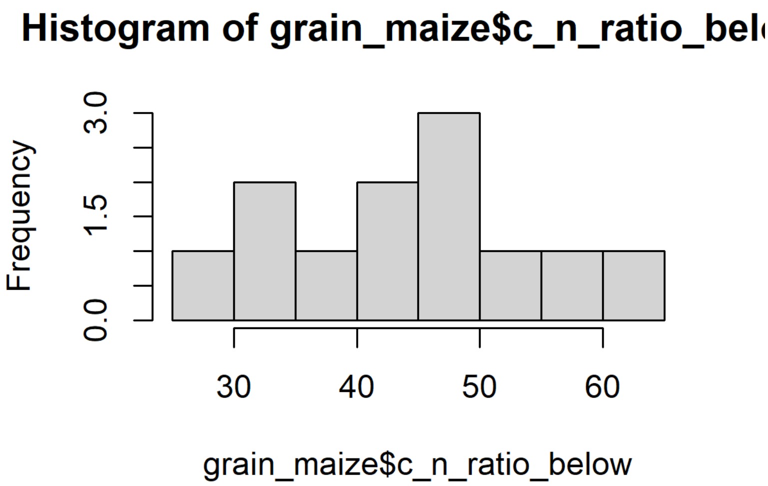



```
Analysis of Variance Table

Response: c_n_ratio_above
                Df  Sum Sq Mean Sq F value  Pr(>F)
year             1  207.15  207.15  2.5535 0.16117
cultivar_variety  4 1431.28  357.82  4.4107 0.05293 .
Residuals        6  486.76   81.13
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   47.3 2.76  6     40.5       54

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```



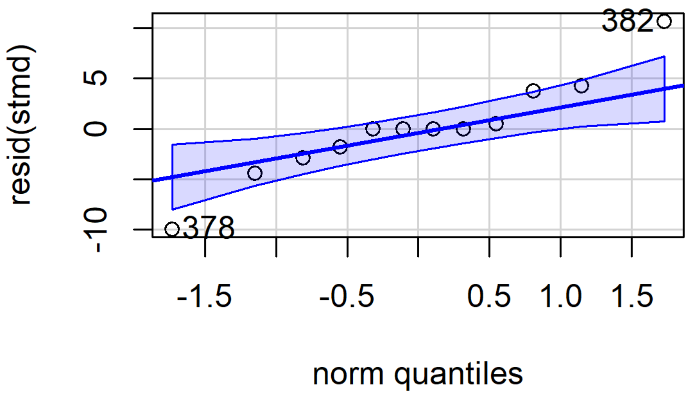

```
381 378
 7   4

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.93543, p-value = 0.4412
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
                 Df Sum Sq Mean Sq F value  Pr(>F)
year              1   0.45   0.451  0.0098 0.92433
cultivar_variety  4 910.27 227.568  4.9474 0.04158 *
Residuals         6 275.99  45.998
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   43.9 2.08  6     38.9       49
```

```
Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```



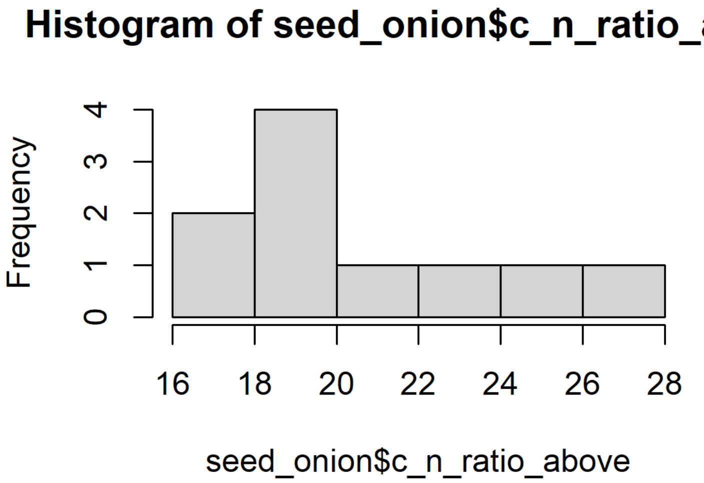

```
382 378
 8   4

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.93815, p-value = 0.4745
```

Summary

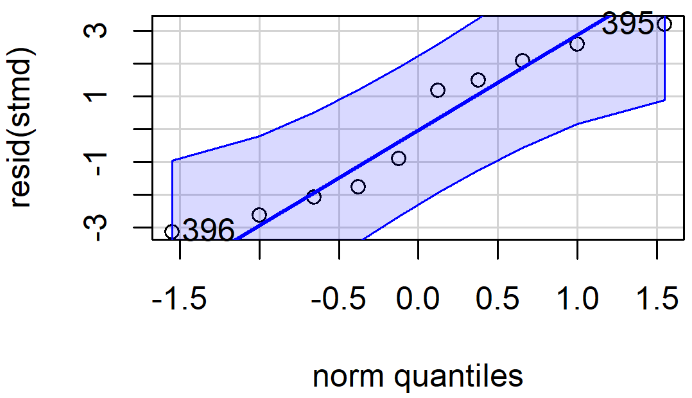
```
# Aboveground
## Number of observations
sum(!is.na(grain_maize$c_n_ratio_above))
 12
# Belowground
## Number of observations
sum(!is.na(grain_maize$c_n_ratio_below))
 12
```

6.28 Seed onion

Aboveground

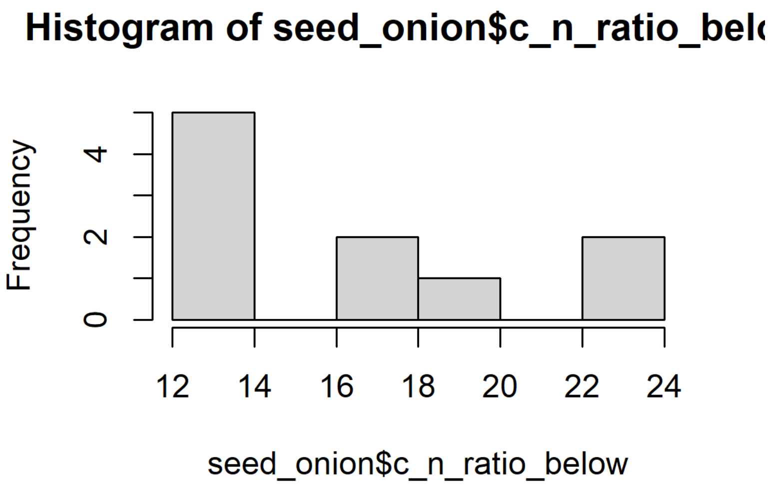



```
Analysis of Variance Table

Response: c_n_ratio_above
                Df Sum Sq Mean Sq F value  Pr(>F)
soil_type        1 39.227  39.227  5.5456 0.05072 .
cultivar_variety  1  3.016   3.016  0.4264 0.53461
Residuals        7 49.515   7.074
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   20.2 0.88  7     18.1     22.3

Results are averaged over the levels of: cultivar_variety, soil_type
Confidence level used: 0.95
```

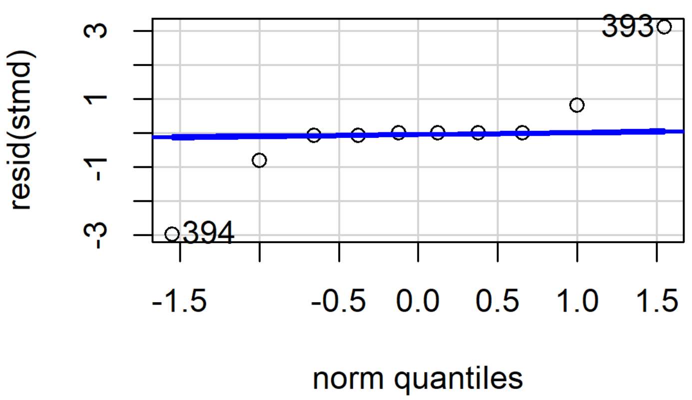



```
395 396
  7   8

   Shapiro-Wilk normality test

data:  resid(stmd)
W = 0.90642, p-value = 0.2573
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
                 Df Sum Sq Mean Sq F value   Pr(>F)
soil_type         1 62.515  62.515  22.138 0.002195 **
cultivar_variety  1 50.312  50.312  17.817 0.003932 **
Residuals         7 19.767   2.824
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   16.8 0.556  7     15.5     18.2

Results are averaged over the levels of: cultivar_variety, soil_type
Confidence level used: 0.95
```




```
393 394
  5   6

	Shapiro-Wilk normality test
```

```
data:  resid(stmd)
W = 0.82648, p-value = 0.03034
```

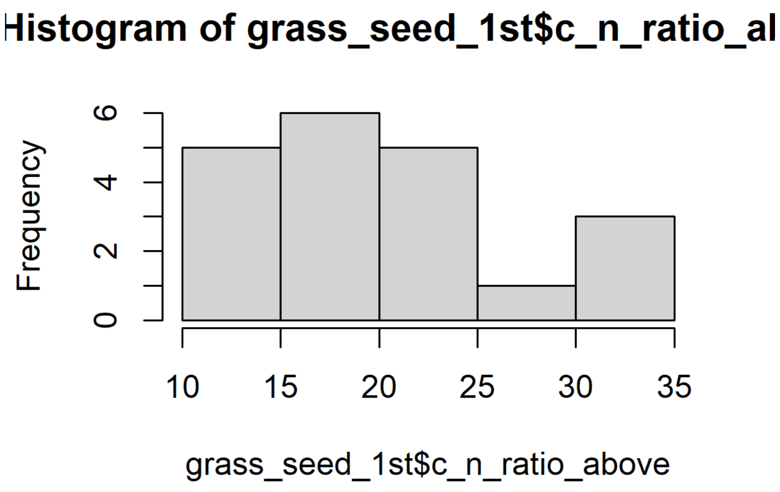
Model does not have normally distributed residues.

Summary

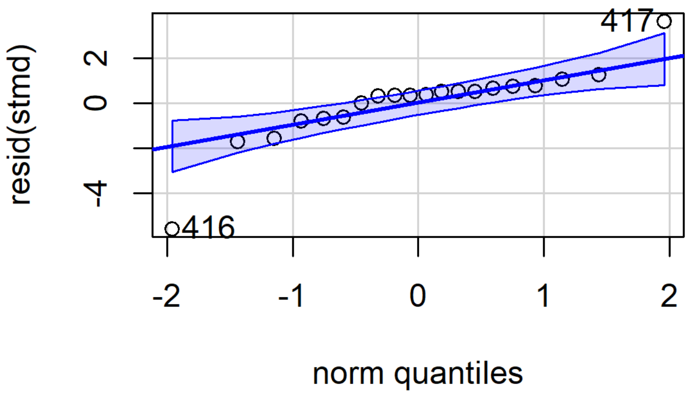
```
# Aboveground
## Number of observations
sum(!is.na(seed_onion$c_n_ratio_above))
 10
# Belowground
## Number of observations
sum(!is.na(seed_onion$c_n_ratio_below))
 10
## Mean
mean(seed_onion$c_n_ratio_below)
 16.84099
## Median
median(seed_onion$c_n_ratio_below)
 15.31279
```

6.29 Grass seed 1st

Aboveground

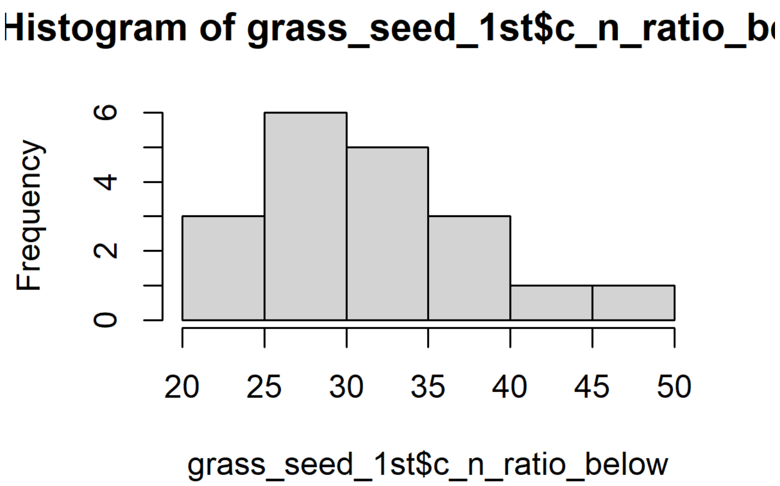



```
Analysis of Variance Table

Response: c_n_ratio_above
              Df Sum Sq Mean Sq F value    Pr(>F)
year             1  62.56  62.564  15.429  0.001516 **
cultivar_variety  4 640.67 160.167  39.500 1.759e-07 ***
Residuals       14  56.77   4.055
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall     19 0.555 14     17.8     20.2

Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```



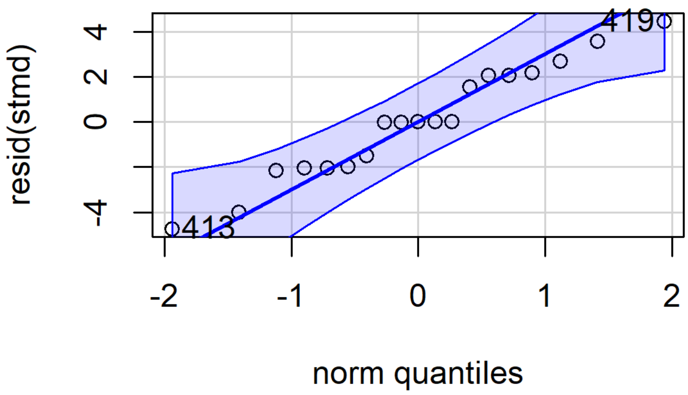

```
416 417
 17  18

	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.22017, p-value = 0.2479
alternative hypothesis: two-sided
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
                 Df Sum Sq Mean Sq F value    Pr(>F)    
year              1 230.57 230.574  26.628 0.0001834 ***
cultivar_variety  4 392.11  98.027  11.321 0.0003518 ***
Residuals        13 112.57   8.659                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   31.8 0.845 13       30     33.7
```

```
Results are averaged over the levels of: year, cultivar_variety
Confidence level used: 0.95
```



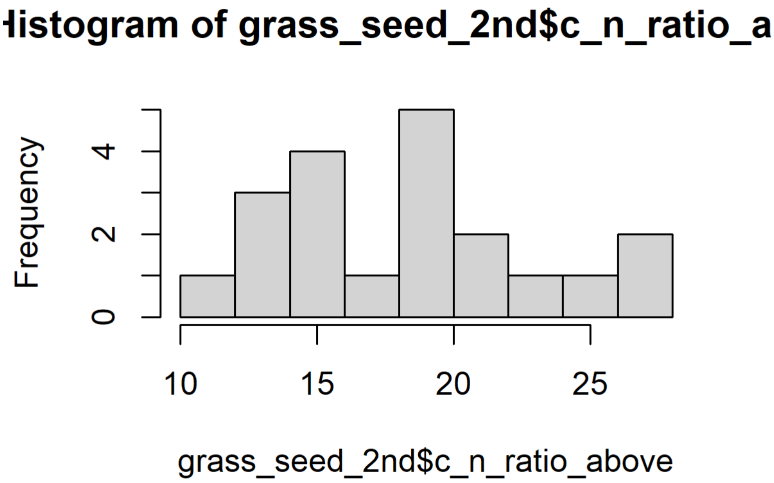

```
413 419
 13  19

   One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.12886, p-value = 0.9106
alternative hypothesis: two-sided
```

Summary

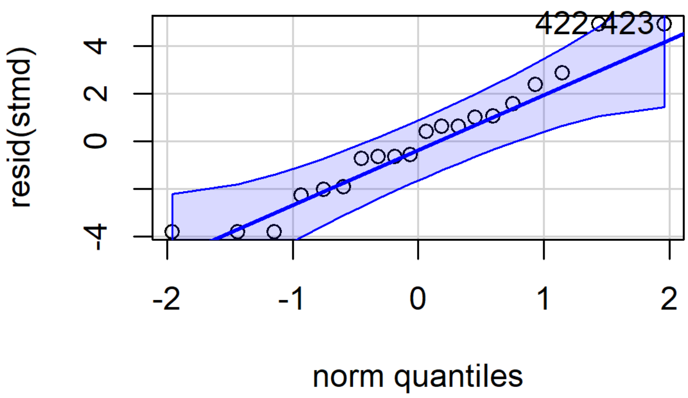
```
# Aboveground
## Number of observations
sum(!is.na(grass_seed_1st$c_n_ratio_above))
 20
# Belowground
## Number of observations
sum(!is.na(grass_seed_1st$c_n_ratio_below))
 19
```

6.30 Grass seed 2nd

Aboveground

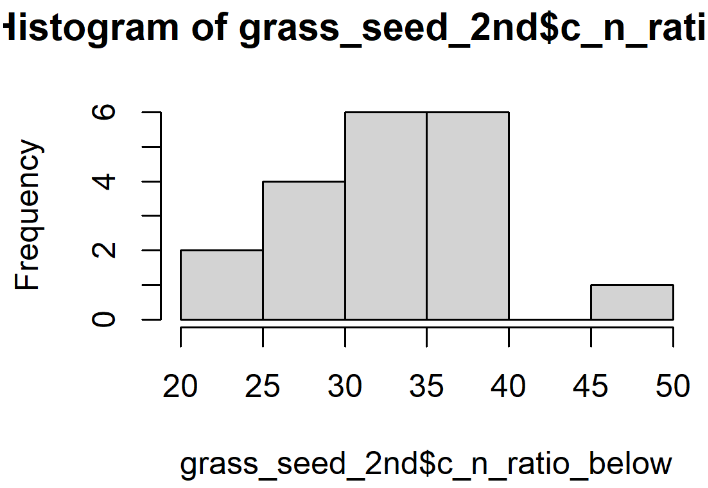



```
Analysis of Variance Table

Response: c_n_ratio_above
                Df Sum Sq Mean Sq F value    Pr(>F)
year             1  49.68  49.680  6.3079 0.0231296 *
cultivar_variety  2 240.70 120.350 15.2810 0.0001944 ***
Residuals       16 126.01   7.876
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean    SE df lower.CL upper.CL
 overall   17.5 0.656 16     16.1     18.9

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```

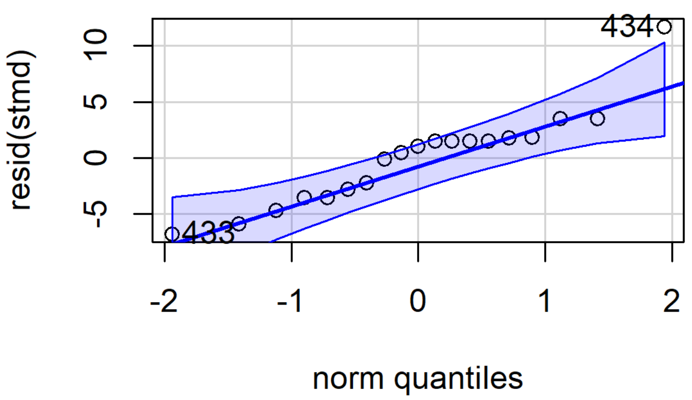



```
423 422
  3   2

    One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.093287, p-value = 0.995
alternative hypothesis: two-sided
```

Belowground




```
Analysis of Variance Table

Response: c_n_ratio_below
                Df Sum Sq Mean Sq F value   Pr(>F)
year             1 270.14 270.139 12.7586 0.002781 **
cultivar_variety  2 198.97  99.486  4.6987 0.026038 *
Residuals       15 317.60  21.173
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 1       emmean   SE df lower.CL upper.CL
 overall   32.6 1.09 15     30.2     34.9

Results are averaged over the levels of: cultivar_variety, year
Confidence level used: 0.95
```




```
434 433
 13  12
```

```
	One-sample Kolmogorov-Smirnov test

data:  resid(stmd)
D = 0.17215, p-value = 0.6265
alternative hypothesis: two-sided
```

Summary

```
# Aboveground
## Number of observations
sum(!is.na(grass_seed_2nd$c_n_ratio_above))
 20
# Belowground
## Number of observations
sum(!is.na(grass_seed_2nd$c_n_ratio_below))
 19
```