ResidueGas DELIVERABLE NO. 1.1 and 1.3

Review of methods for estimating nitrogen and carbon inputs to soils from crop residues

March 2021

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1. Summary

The work on methods for estimating crop residue biomass and N returned on cropped soils examined two original aspects on which data and publications are still limited. The first aspect concerned the horizontal spatial distribution of crop residues on the soil surface (and in the soil), induced by the spatial variability of yields and by cropping operations at harvest. The data available in Denmark, France and Sweden showed that this horizontal spatial distribution is very heterogeneous, and raises questions about the environmental consequences, particularly on N_2O emissions, of this strong heterogeneity under agricultural conditions. The second point concerns the analysis of recent literature on the allocation of plant biomass to root systems, and the possibility of modifying the IPCC equations by substituting fixed values of root mass by species and cropping systems for the current method of allocation by the shoot: root ratio. A number of recent European studies showed that the uncertainty on root masses is lower when considering fixed values than ratios. The literature also shows that these values need to be determined by crop type, practice (fertilised, unfertilised) and climate, which would require a European effort to collect such data prior to providing generic method and default values at the international level.

2. Introduction

To estimate the amount of crop residues left in the field, the IPCC 2006 guidelines provide data based on international literature reviews. They provide equations for integrating the influence of yield on the amount of residues left in the field, and for calculating the contribution of root biomass of these crops, via a root biomass: above-ground biomass ratio. Most of the references to parameterise these equations come from studies based on references from North America, where yields can be quite different from those observed in Europe. In this context the objective of WP1 was to review these quantitative approaches and in particular to provide updated references for crop residue quality across different European countries and different cropping systems.

EQUATION 11.6 (UPDATED)
N FROM CROP RESIDUES AND FORAGE/PASTURE RENEWAL (TIER 1)

$$F_{CR} = \sum_{T} \left\{ \left[AGR_{(T)} \bullet N_{AG(T)} \bullet \left(1 - Frac_{Remove(T)} - \left(Frac_{Burnt(T)} \bullet C_f \right) \right) \right] + \left[BGR_{(T)} \bullet N_{BG(T)} \right] \right\}$$

$$N_2O_{(ATD)} = N_2O_{(ATD)} - N \bullet 44/28$$

$$BGR_T = \left(Crop_{(T)} + AG_{DM(T)} \right) \bullet RS_{(T)} \bullet Area_{(T)} \bullet Frac_{Renew(T)}$$

$$AG_{DM(T)} = Crop_{(T)} \bullet R_{AG(T)}$$

Figure 1: Equation of the IPCC methodology to quantify annual amount of N in crop residues (F_{CR}). The equation reveals the complexity of the calculation and the high requirements in IPCC default values or country-specific values for the parameters of this equation. N in Crop residue relies on terms relating to residue biomass (i.e., $A_{GR(T)}$ $B_{GR(T)}$) and those relating to nitrogen content.(i.e., $N_{AG(T)}$, $N_{BG(T)}$). Default values are given and national inventories may use their specific values. IPCC, 2019.

3. Materials and methods

Task 1.1 aimed at updating and synthetizing methods to quantify the residue N inputs. During the course of the project, it was decided to focus on two potential improvements in the determination of plant residue returns (i) the spatial heterogeneity of the mass and/or amount of nitrogen of plant residues, either resulting from the spatial variability of production and yields or crop operations at harvest. (ii) The estimate of below-ground plant biomasses (root systems) and their relationships with above-ground production for a large range of crops. While the first question relies on experimental data from partners, the second question relies mostly on available literature.

3.1 Characterization of spatial variability of crop residues

The spatial variability of crop residues in /on the soils, was investigated in Denmark and in France. The work carried out in Denmark and Sweden, aimed at determining 1) the within-field variability in straw dry matter production of pea (*Pisum sativum* L.), oat (*Avena sativa* L.) and winter wheat (*Triticum aestivum* L.) in farmers' fields, and 2) the relationship between straw and grain DM yields for eventual management of residues to minimize GHG emissions. We used farmer's field in Denmark and Sweden and established grids of 50 plots within fields of 1-10 ha. .

<u>Field experiment PEA05</u>

We analyzed pea straw and grain dry matter (DM) yields and N-concentration from a conventional 10 ha spring pea field on a sandy loam soil with a sampling grid of 56 points over the field in Roskilde, Denmark (Hauggaard-Nielsen et al., 2010). Additional soil sampling grids were present in this field, in which several soil parameters were sampled and analysed. We sampled 1 m2 plots of pea at maturity in August and determined the DM yield of grain and straw and the nitrogen concentration in crop components.

<u>Field experiments PEA_OAT19 and WHEAT19</u>

In the PEA_OAT19 field experiment, we determined DM yields of pea and oat across a 1 ha field from 50 sampling points for each crop at Alnarp, Sweden, in 2019. The field was part of a conventional cropping system, but no herbicides were used in the experiment. We sampled 1 m^2 plots of pea and oat at maturity in August and determined the DM yield of grain and straw of pea and oat. The field experiment was part of an intercrop experiment to study ecological precision farming and further details on soil and plots can be found in Dhamala et al. (2021). The WHEAT19 field experiment was made as a transect in an established conventional farmers' winter wheat field in 2019 at Alnarp, Sweden. The sampling transect is 1.6 ha (40m x 400m) and covers an altitude range of approx. 3-8 meters above sea level (Fig.1). We sampled 1 m^2 micro plot at 50 points in the transect. The winter wheat was threshed and dried to determine DM of grain and straw.

Figure 2: WHEAT19 transect of 1.6 ha with 50 sampling points of winter wheat. Photo Ryan Davidson, SLU

<u>Fields experiments under conservation agriculture in Grand-Est region (France)</u>
The experimental work carried out in eastern France, aimed at characterizing the spatial variability in farmer's field, in conservation agriculture, with the measurement of mulch masses of pea, and oilseed rape and mulch thickness for maize crop. The estimates of mass was done by collecting the biomass left using a micro plot approach across several transects perpendicular to the advancement line of the harvester combiner. The estimates of mulch thickness was performed using an asperimeter over a harvest width replicated four time (Thiébeau, 2019).

3.2 Literature analysis of biomass allocation and root: shoot ratios

The relevance of the equations to inform the mass and quality of crop residues was discussed throughout the project by the partners involved. The comparison of the proposed default references between the IPCC and the data of each country is carried out in WP5. It appears that the data differ significantly in terms of yield levels, nitrogen fertilization intensities and harvesting methods between countries, which modify the ratio residue: yield, the amount of mass exported vs. returned, the average N content values of the residues.
The country-specific values of parameters are provided in national documents (e.g., with France or UK, see WP5). The project examined the published literature, selecting work examining root and shoot masses and discussing C allocation in crops. The most relevant articles were selected.

$RS_{(T)}$	= ratio of below-ground root biomass to above-ground shoot biomass for crop T, kg d.m.ha^{-1} (kg d.m. ha^{-1})$^{-1}$, (Table 11.1a)
T	= crop or forage type

Figure 3: Term of the IPCC equation used to calculate the belowground biomass (BGR_T) as a function of root: shoot ratio. IPCC, 2019.

4. Results and discussions

4.1 Spatial variability of crop residue biomasses in field

In the Danish and Swedish experiments, we found a significant within-field variability of the pea, oat and winter wheat straw yields (several tons DM/ha) even in fields of only 1 ha (Fig.4). The results showed also a linear relationship between the grain and straw yields of pea, oat and winter wheat in farmers' fields as previously reported (Fig.5). The slope of the regression indicated that the straw yield of pea could be approximated by multiplying the grain with a factor of 0.64 or 0.87, depending on the context. For OAT19 and WHEAT19, the factor was very similar and close to 0.7. This linear relationship between grain and straw yields of the three crops, indicating a potential for determining part of the field with high and low straw production based on a combiner yield meter and GPS.

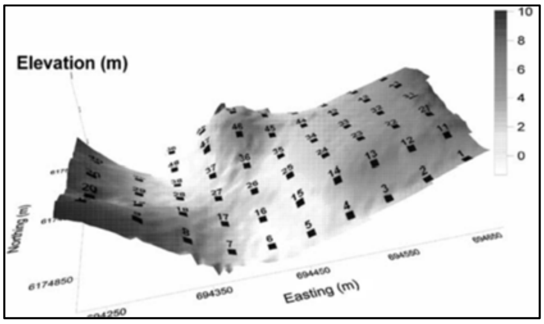

Figure 4: Topographic map of the 10 ha PEA05 field, with sampling plot locations. Elevation, in meters above sea level. From Hauggaard-Nielsen et al. (2010).

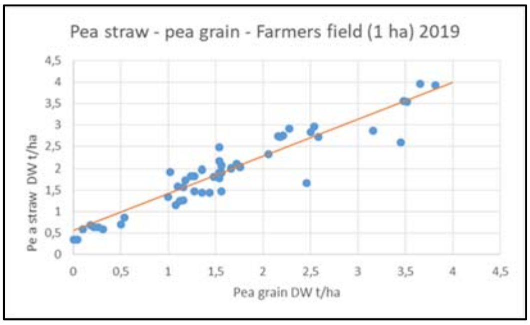

Figure 5: PEA19 - regression of pea straw on pea grain yields. *(b=0.871, r2= 0.94)*

We hypothesized that the higher the grain yield the higher would be the mobilization of N from vegetative pea plant parts (straw) and thus leading to a lower N-concentration in straw. We did not find support for this hypothesis in the relationship between the pea grain yield and the N-concentration in straw in PEA05, although earlier observations have indicated that there may be a negative correlation between the pea grain yield and the straw N-concentration (Jensen, 1989).

Thus, in the context of precision farming, where farmers may use a yield meter and GPS on their combiner, they can identify the part of the field with very high or very low straw yields. This knowledge may open up for management of the straw, e.g. by removal or spreading over a larger area of high amounts of residue. However to make more precise estimates of straw yields based on the grain yield, several years of field experiments with different cultivars and fertilization would be required.

In the French experiments, the estimates of residue masses left on to the soil in no-tilled systems, showed for example that the mean mass of pea residues at 200 g m^{-2} varied from about 50 to 350 g m^{-2} according to position in the field (Fig. 6). For the oilseed rape experiment, the mean 1130 g m^{-2} varied in the range 500 to 1600 g m^{-2}, with a pattern of heterogeneity designed by the axis of advancement of the harvester combiner. The thickness of the maize mulch co-varied with mass, from about 10 mm thick to 80 mm thick, with a pattern showing again the impact of the harvester combiner on the residue distribution (Fig. 6).

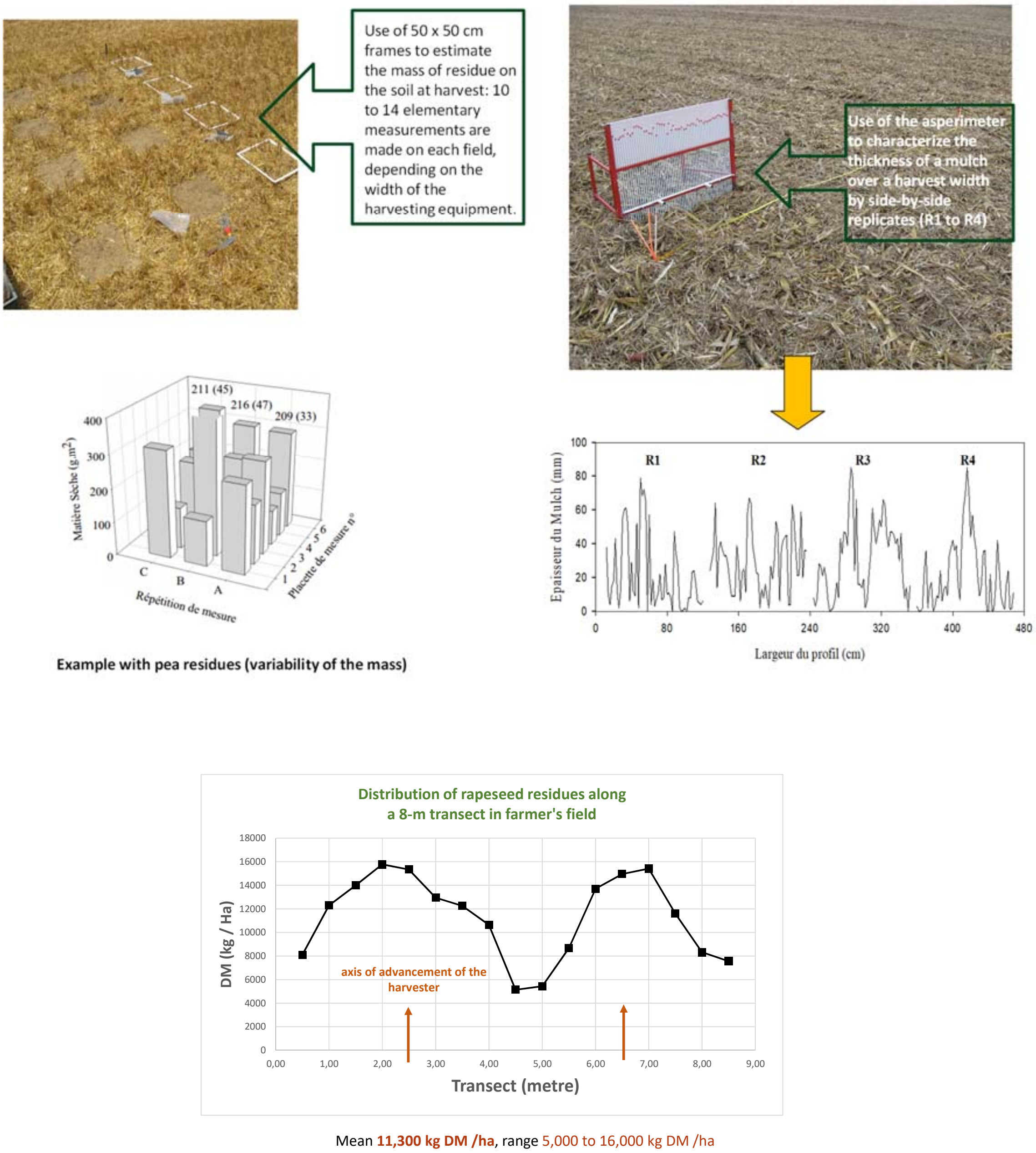

Figure 6: Field spatial variability in the distribution of pea and oilseed rape residues, and the changes in mulch thicknesses with maize mulch. The residue biomasses were collected from micro plots distributed according to the harvest pattern. The measurement of the mulch thickness was done across 4 adjacent transects, using an adapted asperimeter.

These results confirmed the Danish ones showing that a large spatial heterogeneity in the distribution of crop residues, may exist in the farmer's fields, as a result from both the heterogeneity in plant production, and the post-harvest distribution gradients linked to the spreading of residues at harvesting time. The characterization of horizontal distribution of crop residues were very rarely done in field conditions under farmer's practices, while data are slightly more frequent on the vertical distribution in relation to the type of tillage. Jani et al. (2019) looked at the consequences of heterogeneous distribution of residues with peanut production, to estimate variability on the subsequent nitrogen mineralization. Lowry and Brainard (2016) investigated how strip-intercropping of Rye-Vetch mixtures affected spatial distribution of cover crop residue.

Therefore we believe that the agricultural and environmental consequences of such heterogeneity in distribution have been underestimated, leading in particular to heterogeneity in the subsequent supply of nutrients from the soil to the crop, and leading to areas of residue accumulation which may be favorable conditions for emissions in particular of N2O. This opens the possibility for crop residue management to minimize emissions of N_2O. Investigation with soil-crop C-N models should be run in the future to examine the sensitivity of the response of N fluxes and particularly N_2O emission to residue mass, on an area basis.

4.2 Improvement of root biomass estimations

The literature investigation on the allometric relationships between above-ground (AGB) and below- ground (BGB) biomasses focused on synthesis studies with sufficient data to derive general laws. However, few results are available in the recent literature, due to the experimental difficulties to quantify in situ root systems, and, despite the increasing interest for root systems, the recent literature is more oriented towards the contribution of root C to soil, than to the plant allometric relationships. Root: shoot ratio (R/S) usually is thought to reflect the differential investment between AGB and BGB induced by abiotic and biotic factors, and therefore in many experimental data, R/S responds to factors such as nutrient availability (i.e., fertilization) and climatic conditions (inter-annual variability) (Yang et al., 2018). The most notable recent results is the work of Hu et al. (2018) showing that for example for cereals (wheat and barley) across a large range of farming systems and years in Denmark, the fixed root biomass based on the most influential factors (farming system and species) provided the lowest error of prediction for estimation of root biomass, compared with the use of fixed allometric relationships such as root/shoot ratio. This conclusion applied also to catch crops and weed roots. The conclusion that yield-independent values provided closer estimates for below-ground carbon inputs to soil of cereals in different farming systems than yield-based functions was also reached by Hirte et al. (2018) in two Swiss long-term field trials comparing different farming systems (bio-organic, conventional) and fertilization treatments (zero, manure, mineral). It suggests that the equation for calculating the root biomass could be replaced by average values for root biomass per type of species, reducing the uncertainty linked to the cascading use of the equation terms which all have associated uncertainties. Taghizadeh-Toosi et al. (2020) have adopted a modelling strategy to examine this question with grass leys. They used the C-TOOL model to evaluate the hypothesis of the root biomass being independent of the above-ground biomass production (from fixed shoot-to-root ratios to fixed belowground C input) and compared simulated carbon data with observed data from several long-term experimental series (Sweden, Denmark, UK, Switzerland). They showed that changing this allometric approach improved the simulation of SOC stocks for fertilized treatments but decreased it for unfertilized treatments. Jacobs et al. (2020) quantifying exports and inputs of organic carbon on agricultural soils in Germany, used field management data surveyed within the Agricultural Soil Inventory with about 27500 cases (sites x years). They found that organic C input to soil was strongly driven by total net primary production (NPPtot), with on average 25% of the NPP_{tot} was allocated to roots and rhizodeposition (NPP_{below}) of main crops and cover crops. However their recognize that the application of a yield-dependent ratio of NPP_{above} to NPP_{below} would most likely cause large errors for the estimation of NPP_{below} compared to using a fixed value for belowground input, provided regionally sound values for NPP_{below} are available.

These recent comprehensive studies do not, however, allow us at the moment to free ourselves from the particular situations in which they were conducted in order to modify the proposals of the IPCC method. The recent results argue for a research effort on this issue, and it will also be useful to better characterize root litters from a chemical point of view (nitrogen content and decomposability) in order to potentially adapt the emission factors for this type of litter, if necessary.

5. Conclusions

The experimental data acquired and the review of recent literature show two ways to improve the consideration of crop residues as a source of nitrogen for N_2O emissions

- A knowledge of the spatial heterogeneity of the distribution of the crop residues in the field under agricultural conditions, and its effects on the risks of emissions;
- An improvement in the estimation of crop root biomass, by substituting constant values of root mass per species group and/or per type of cropping system, for present equations based on the Root: Shoot ratio.

These two avenues require research efforts, particularly experimental ones, coordinated on a European scale, so as to be able to propose changes to emission inventories in the long term. With regard to heterogeneity, reducing it in the field, both to reduce hot spots and to homogenise subsequent soil nitrogen mineralisation, opens up management prospects for GHG mitigation.

The project initially intended to propose a review paper (1.3) on these methods. After screening the literature, there was no enough published data and associated papers to prepare a review about post-harvest spatial horizontal variability of crop residues. Regarding the estimate of plant belowground biomasses, several very recent articles were published over the years 2018-2020, in specific contexts but with analysis of large datasets, therefore there was not enough new information (ResidueGas focus was not on root biomass measurements and C allocation in plants) or renewed point of view to write a review article.

6. References

Dhamala NR, Chongtham IR, Jensen ES, (2021) Intercropping of oat and pea to address field-scale soil heterogeneity. Aspects of Applied Biology, 146 (In press)

Engel RE, Long DS, Carlson GR., (2003) Predicting Straw Yield of Hard Red Spring Wheat. Agronomy Journal, 95:1454-1460. https://doi.org/10.2134/agronj2003.1454

Hauggaard-Nielsen H, Holdensen L, Wulfsohn D, Jensen ES, (2010) Spatial variation of N2-fixation in field pea (Pisum sativum L.) at the field scale determined by the 15N natural abundance method. Plant and Soil 327, 167-184. https://doi.org/10.1007/s11104-009-0043-9

Hirte J, Leifeld J, Abiven S, Mayer J. (2018) Maize and wheat root biomass, vertical distribution, and size class as affected by fertilisation intensity in two long-term field trials. Field Crops Research 216, 197-208. https://doi.org/10.1016/j.fcr.2017.11.023

Hu T, Sorensen P, Wahlström EM, Chirinda N, Sharif B, Li X, Olesen JE. (2018) Root biomass in cereals, catch crops and weeds can be reliable estimated without considering aboveground biomass. Agriculture Ecosystems and Environment 251, 141-148. https://doi.org/10.1016/j.agee.2017.09.024

IPCC, 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — IPCC

Jacobs A, Peoplau C, Weiser C, Nitschhke AF, Don A. (2020) Exports and inputs of organic carbon on agricultural soils in Germany. Nutrient Cycling in Agroecosystems, 118, 249-271. https://doi.org/10.1007/s10705-020-10087-5

Jani AD, Mulvaney MJ, Enloe HA, Erickson JE, Leon RG, Rowland DL, Wood CW. (2019) Peanut residue distribution gradients and tillage practices determine patters of nitrogen mineralization. Nutrient Cycling in Agroecosystems 113, 63-76. https://doi.org/10.1007/s10705-018-9962-2

Jensen ES, (1989) The role of pea cultivation in the nitrogen economy of soils and succeeding crops. In: Legumes in farming systems (Plancquart, P. and R. Haggar, eds.), pp. 3- 15. Kluwer Academic Press, Dordrecht

Lowry CJ, Brainard DC. (2016) Strip-Intercorpping of rye-vetch mixtures affects biomass, carbon/nitrogen ratio, and spatial distribution of cover crop residue. Agronomy Journal 108, 2433-2443. https://doi.org/10.2134/agronj2016.04.0189

Taghizadeh-Toosi A, Cong W, Eriksen J., et al. (2020) Visiting dark sides of model simulation of carbon stocks in European temperate agricultural soils: allometric function and model initialization. Plant Soil 450, 255–272. https://doi.org/10.1007/s11104-020-04500-9

Thiébeau P, Millon F, Beaudoin N. (2011). Conception d'un aspérimètre pour mesures aux champs. Les Cahiers des Techniques de l'INRA 72: 37–58.

Thiébeau P, (2019) Mesurer l'épaisseur des résidus à la surface d'un sol pour estimer leur biomasse. Cahiers Agriculture 28, 11. https://doi.org/10.1051/cagri/2019011

Thiébeau P, Recous S. (2016). Méthode pour quantifier les biomasses de résidus de récolte à la surface des sols après la moisson. Cahiers Agricultures 25: 45001. https://doi.org/10.1051/cagri/2016027.

Yang Y, Dou Y, An S, Zhu Z. (2018) Abiotic and biotic factors modulate plant biomass and root/shoot (R/S) ratios in grassland on the Loess Plateau, China. Science of the Total Environment 636, 621-631. https://doi.org/10.1016/j.scitotenv.2018.04.260

7. Appendix A

Variability of crop residues across farmers' fields
Report on the SLU contribution to WP1
in the FACCE ERA-GAS project ResidueGas

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Variability of crop residues across farmers' fields

Abstract

Grain and straw yields, as well as their qualities, vary across farmer's field. This variability may potentially influence the C-N cycling during the decomposition of crop residues. Our aim was to determine 1) the within-field variability in straw dry matter production of pea (*Pisum sativum* L.), oat (*Avena sativa* L.) and winter wheat (*Triticum aestivum* L.) in farmers' fields and 2) the relationship between straw and grain DM yields for eventual management of residues to minimize GHG emissions. We used farmer's field in Denmark and Sweden and established grids of 50 plots within fields of 1-10 ha. We found significant variability in straw yields even within 1 ha fields and a linear relationship between grain and straw yields. This shows that there is a potential for determining parts of the field with high and low straw production based on combiners with yield meters and GPS equipment. This opens the possibility for crop residue management to minimize emissions of CO_2 and N_2O. The variability of straw yields may potentially be considered in models to make more precise estimates of the effects of crop residues on the emission of CO_2 and N_2O.

Introduction

It is well-known that crop yields vary across a farmer's field depending on the interactions between crop species, climate, soil, topography and crop management. There is also evidence of linear relationships between grain and straw yields, but the relationship may vary with pedo-climatic conditions and cultivar (Engel et al., 2003). This knowledge has prompted the interest in site-specific management of the field crops by so-called precision farming technology. Similarly, the amount and quality of crop residues may influence the C-N cycling of crop residues, including the emission of CO_2 and N_2O.

The aims of this study are to determine 1) the within-field variability in straw dry matter production of spring pea, spring oat and winter wheat in farmers' fields in Denmark and Sweden, and 2) the relationship between straw and grain DM yields for eventual management in a precision farming context of residues in parts of a field to minimize N_2O emissions.

Materials and methods

Field experiment PEA05

We analyzed pea straw and grain dry matter (DM) yields and N-concentration from a conventional 10 ha spring pea field (Fig. 1) on a sandy loam soil with a sampling grid of 56 points over the field in Roskilde, Denmark (Hauggaard-Nielsen et al., 2010). Additional soil sampling grids were present in this field, in which several soil parameters were sampled and analyzed. We sampled 1 m^2 plots of pea at maturity in August and determined the DM yield of grain and straw and the nitrogen concentration in crop components. Straw DM yields and N-

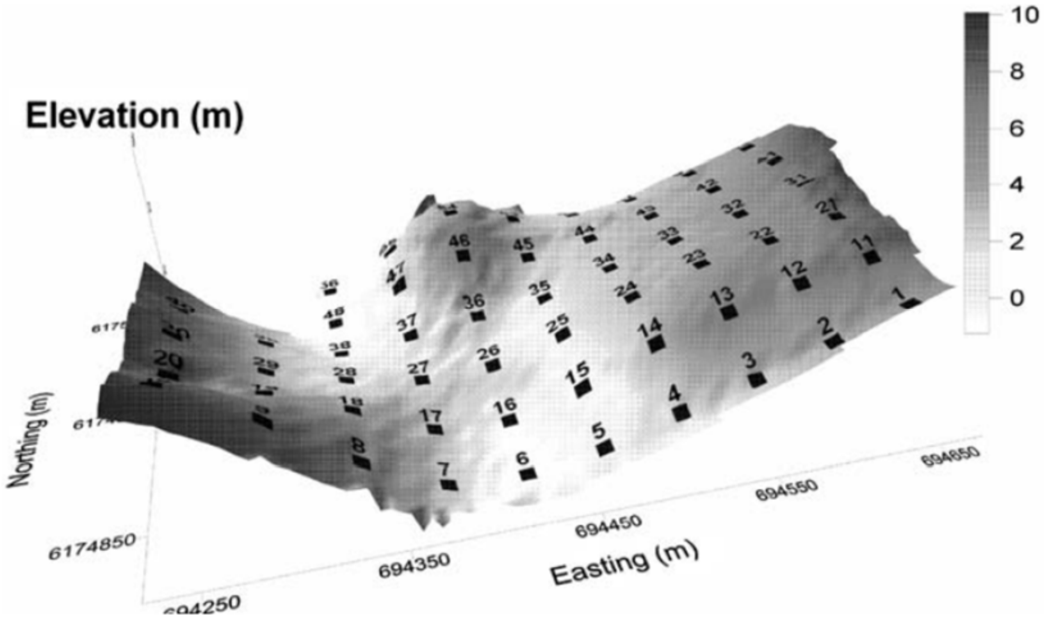

Fig. 1 Topographic map of the 10 ha PEA05 field, with sampling plot locations. Elevation, in meters above sea level. From Hauggaard-Nielsen et al. (2010).

concentrations in straw have not been published. Further details are found in Hauggaard-Nielsen et al. (2010).

<u>Field experiments PEA_OAT19 and WHEAT19</u>

In the PEA_OAT19 field experiment, we determined DM yields of pea and oat across a 1 ha field from 50 sampling points for each crop at Alnarp, Sweden, in 2019 (Fig. 2). The field was part of a conventional cropping system, but no herbicides were used in the experiment. We sampled 1 m^2 plots of pea and oat at maturity in August and determined the DM yield of grain and straw of pea and oat. The field experiment was part of an intercrop experiment to study ecological precision farming and further details on soil and plots can be found in Dhamala et al. (2021).

The WHEAT19 field experiment was made as a transect in an established conventional farmers' winter wheat field in 2019 at Alnarp, Sweden (Fig. 3). The sampling transect is 1.6 ha (40m x 400m) and covers an altitude range of approx. 3-8 meters above sea level. We sampled 1 m^2 micro plot at 50 points in the transect (Fig. 3). The winter wheat was threshed and dried to determine DM of grain and straw.

Results and Discussion

<u>PEA05</u>

The pea grain yield varied between 2.2 and 7.2 t/ha within the 10 ha (Fig. 4) and the straw DM yield between 2.2 and 6.7 t/ha (Table 1). There is a linear relationship between grain and straw DM yields, but at the lower grain yield levels the straw yield was quite variable, *e.g.* at approx. 3.2 t/ha grain the straw yield may vary between 2.2 and 5.6 t/ha.

Fig. 2. PEA_OAT19 field experiment (approximately 1 ha) with five strips of sole cropped and intercropped oat and field pea in SLU Alnarp, Sweden, was performed to test the ecological precision farming principle in the Horizon 2020 ReMIX project. The experiment had five blocks of three strips (pea sole crop, oat sole crop, and 50:50% pea:oat intercrop in the seed mixture). Each strip was divided into 10 plots, resulting in 50 plots of each crop within the experimental area. Only pea and oat data were used in this study. Photo: Ryan Davidson, SLU.

Fig. 3. WHEAT19 transect of 1.6 ha with 50 sampling points of winter wheat. Photo Ryan Davidson, SLU

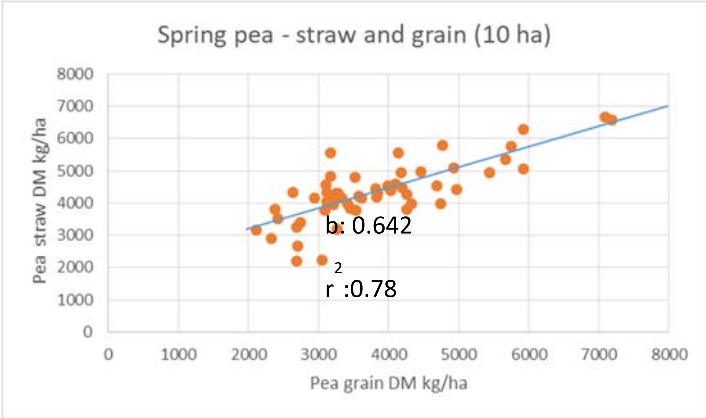

Fig. 4. PEA05 – regression of pea straw on pea grain yields.

The N-concentration of crop residues will influence the C-N dynamics after the incorporation of residues in the soil. Consequently, we also wanted to determine if the straw N-concentration was related to grain yield (Fig. 5). The N-concentration varied between 0.65 and 1.40 within the field, but there was no significant relationship between pea grain yield and the straw N-concentration.

<u>PEA19</u>

The pea grain yield was more variable across the field (Fig. 6) in the PEA19 field experiment than in the PEA05, probably due to more weeds, since there was no weed management in PEA19. However, also in the PEA19, there was a linear relationship between grain and straw DM yields (Fig. 6 and Table 1).

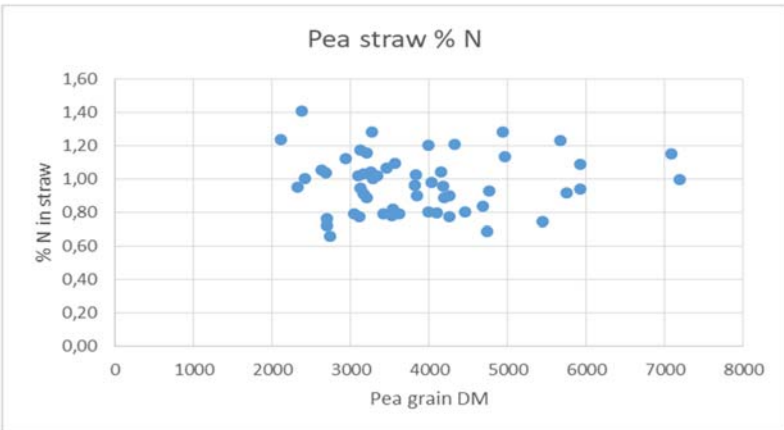

Fig. 5. PEA05. Relationship between pea grain yield (t/ha) and the N concentration in pea straw.

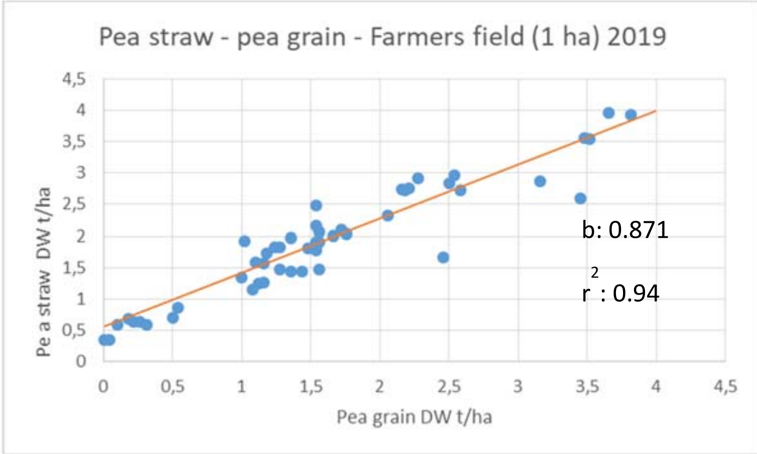

Fig. 6. PEA19 - regression of pea straw on pea grain yields.

OAT19

The oat straw yield was less variable across the field than peas (Fig. 6 and 7), probably due to a better competitive ability towards weeds from oat. There was also a linear relation between the oat grain and straw yields (Fig. 7 and Table 1).

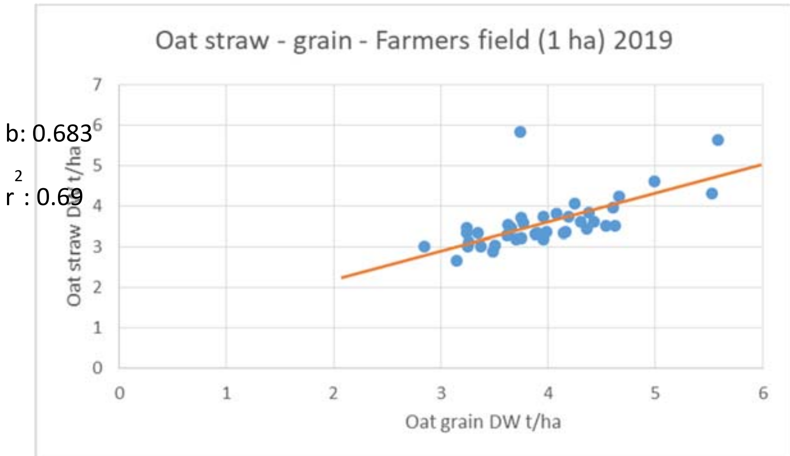

Fig. 7. OAT19 – Regression of oat straw dry matter yields on oat grain yields.

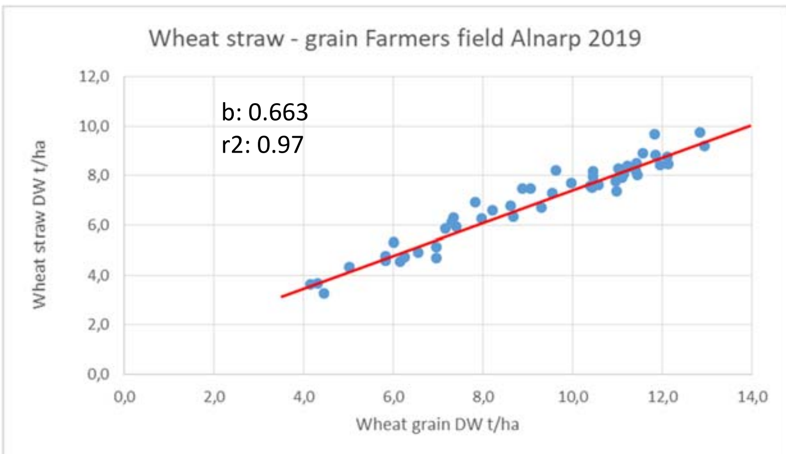

Fig. 8. WHEAT19 - Regression of winter wheat straw yields on grain yields.

WHEAT19

The winter wheat grain and straw yields varied with factors 3.1- 3.2 within the area of 1.6 ha, with straw yields ranging between 3.5 and 9.8 t/ha (Fig. 8). There is a strong linear relationship between grain and straw yield (Fig. 8 and Table 1).

Table 1. Summary of regressions of straw DM yields on grain DM yields from the four field experiments with minimum and maximum straw production and regression components.

Field experiment	Min-Max straw dm (t/ha)	Slope (b) regression straw on grain yield	Inter-cept	r^2
PEA05	2.2 – 6.7	0.64	1.9	0.78
PEA19	0.3 – 4.0	0.87	0.5	0.94
OAT19	2.5 – 5.8	0.68	0.9	0.69
WHEAT19	3.3 – 9.7	0.66	0.9	0.97

Discussion

The results showed a linear relationship between the grain and straw yields of pea, oat and winter wheat in farmers' fields as previously reported (Engel et al.,2003). The slope of the regression indicated that the straw yield of pea could be approximated by multiplying the grain with a factor of 0.64 or 0.87, depending on the context. For OAT19 and WHEAT19, the factor was very similar and close to 0.7.

Thus, in the context of precision farming, where farmers may use a yield meter and GPS on their combiner, they can identify the part of the field with very high or very low straw yields. This knowledge may open up for management of the straw, *e.g.* by removal or spreading over a larger area of high amounts of residue. To make more precise estimates of straw yields based on the grain yield, several years of field experiments with different cultivars and fertilization are required.

We hypothesized that the higher the grain yield the higher would be the mobilization of N from vegetative pea plant parts (straw) and thus leading to a lower N-concentration in straw. We did not find support for this hypothesis in the relationship between the pea grain yield and the N-concentration in straw in PEA05, although earlier observations have indicated that there may be a negative correlation between the pea grain yield and the straw N-concentration (Jensen, 1989).

Conclusions

- We found a significant within-field variability of the pea, oat and winter wheat straw yields (several tons DM/ha) even in fields of only 1 ha.
- There is a linear relationship between grain and straw yields of the three crops,indicating a potential for determining part of the field with high and low straw production based on a combiner yield meter and GPS. This opens the possibility for crop residue management to minimize emissions of N_2O.
- The variability of straw yields may potentially be considered in models for improving the estimates of crop residues effect on emissions of CO_2 and N_2O.

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References

Dhamala, N.R.; Chongtham, I.R. and Jensen, E.S. 2021. Intercropping of oat and pea to address field-scale soil heterogeneity. Aspects of Applied Biology, 146 (In press)

Engel, R.E., Long, D.S. and Carlson, G.R. 2003. Predicting Straw Yield of Hard Red Spring Wheat. Agron. J. 95:1454–1460.

Hauggaard-Nielsen, H., Holdensen, L., Wulfsohn, D. and Jensen, E.S.. 2010. Spatial variation of N_2-fixation in field pea (Pisum sativum L.) at the field scale determined by the ^{15}N natural abundance method. Plant and Soil 327, 167-184.

Jensen, E.S. 1989. The role of pea cultivation in the nitrogen economy of soils and succeeding crops. In: Legumes in farming systems (Plancquart, P. and R. Haggar, eds.), pp. 3- 15. Kluwer Academic Press, Dordrecht

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