Slutrapport

Uppskatta vallens avkastning och näringsinnehåll genom spektral teknik

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Del 1: Utförlig sammanfattning

I norra Sverige används nära 80% av den odlingsbara marken till flerårig vall för användning i animalieproduktionen. När lantbrukaren ska avgöra lämplig tid för skörd görs en avvägning mellan näringsvärde och skördad mängd, oftast baserat enbart på den egna erfarenheten. För att få mer objektiva, snabba och precisa beslutsunderlag har vi i detta projekt utvecklat metoder för att använda fjärranalys vid insamling av information om en grödas näringsinnehåll och avkastning.

Vi har testat ett antal olika typer av utrustning och analyser. Yara N-Sensor kunde med gott resultat kalibreras för mätning av såväl mängden stående gröda som dess innehåll av protein. Denna sensor, liksom annan liknande utrustning, har också testats för skattning av andra mått på foderkvalitet i stående gröda. Vi har också provat en ultraljudssensor för att på avstånd skatta höjden hos ett vallbestånd. En annan metod som har provats är att analysera bilder tagna med mobilkamera för att bestämma grödans botaniska sammansättning. Detta innebar användning av s.k. deep learning-teknik för att träna datorn att korrekt urskilja klöverplantorna i en vallblandning.

Våra resultat kommer att utvecklas vidare för att vara till hjälp för lantbrukare att fatta bra beslut, exempelvis för att bedöma om det är dags att skörda en vall, eller att underlätta beslut rörande gödsling baserat på vallens klöverhalt.

Projekt har fått finansiering genom:
Stiftelsen Lantbruksforskning

Del 2: Rapporten

Introduction

In Northern Sweden, nearly 80% of arable land is used for perennial forage crops. Farmers make decisions on the timing of forage harvests based on assessment of forage nutrition for ruminants. The conventional way to accurately determine forage quality is by laboratory analysis, which is expensive and does not enable rapid decision making. Forage yield is also an important agronomic variable for feed budgeting and planning of management decisions. In addition, botanical composition (BC, the percentage by weight of legume in the legume-grass mixture) is a very important variable, used for quality evaluation, fertiliser application rates, and decision making around crop rotations. However, BC is currently estimated visually, which is often inaccurate. To address these issues, this project aimed to estimate forage quality, yield and BC using a range of remote sensing methods and tools.

Remote sensing (RS) platforms based on the use of hand-held sensors (e.g. smart phone) or UAV (unmanned aerial vehicles) offer an alternative approach for in-field crop quality and yield monitoring, given their flexibility of operation and high throughput. This project explored the usage of different remote sensors to evaluate forage crop characteristics.

Materials and methods

Red clover and timothy were used as the crop species for the current project. To investigate the applicability of remote sensors on forage quality and botanical composition, plant sampling and remote sensing measurement was conducted at several sites in Northern Sweden (Röbäcksdalen, Öjebyn, Lannas and Ås) across 3 years (2017-2019). Measurements were conducted at both established field experiments and randomly selected spots in production fields. For each measurement, the sample spot was selected and delineated using a round hoop (50-cm diameter). The following measurements were conducted for each sample spot: 1. A photo was taken with a smart phone camera; 2. Yara-N sensor was used to collect the canopy spectral signature from 400 to 1000 nm with resolution of 10 nm; 3. ASD Fieldspec was used to collect hyperspectral reflectance data; 4. Ultrasonic sensor measurement was taken (used to derive the sward height). The sensor was mounted at the top of a photography tripod and adjusted to be levelled in order to take vertical measurements; 5. Sward height was also measured manually using a ruler; 6. An electrical grass trimmer was used to harvest the sample area.

Manual separation of legume and grass species was conducted in the laboratory to determine the botanical composition. Fresh samples were dried at 60°C for 48 h. Dried samples was ground to pass a 1-mm screen. Subsequently, selected samples were sent for forage nutritional analysis by wet chemistry methods. All three years of analysis were done at the same lab, to ensure the comparability of the analysis results. In total, 337 spots/samples were taken across three years, which consisted of different development stages, harvests and sites. This made the built estimation models more robust and representative.

Results and discussion

Crop height by ultrasonic sensor

Average grass height measured using a ruler (x-axis) was highly correlated with the ultrasonic sensor reading (y-axis) (Fig.1). The data was collected from 2017 and 2018, across different growth stages and sites in Northern Sweden, suggesting that the ultrasonic sensor is a robust tool suitable for estimating grass height. These results were published as a conference paper (Zhou and Parsons, 2018). Because forage crop height is correlated with forage quality (e.g. NDF) (Parsons et al., 2006), and forage height can also be linked with standing biomass, the ultrasonic sensor is a potential candidate for assessing forages, possibly in combination with other RS methods.

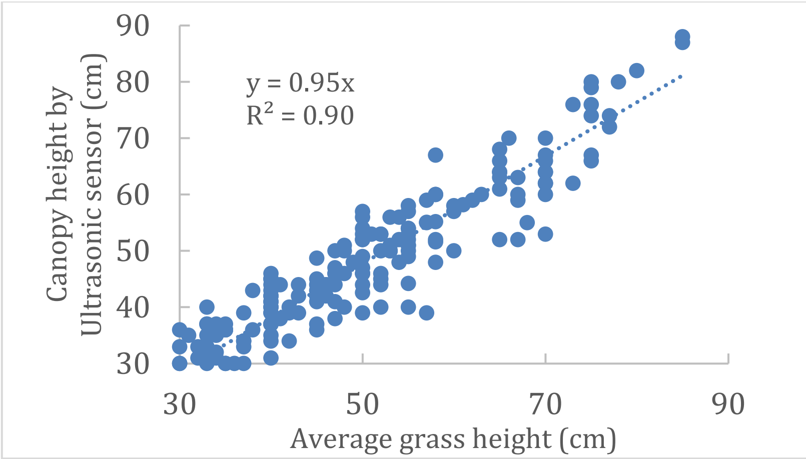

Fig. 1 The relationship between average grass height measured by ruler and estimated by ultrasonic sensor. The equation within the figure is the fitted linear relationship between the two variables.

Yield and crude protein estimated by hyperspectral methods

The Yara N-Sensor is an already commercialised device normally installed on top of a tractor. The sensor used in this project was a hand-held device, but with the same sensor as the tractor-mounted equipment (Fig. 2).

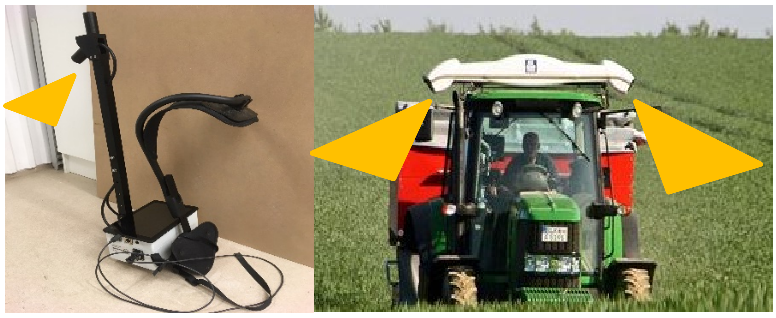

Fig. 2. Left: the hand-held sensor used in this project (Photo: Zhenjiang Zhou). Right: the tractor-mounted Yara N-Sensor (Photo: Yara company homepage). The white instrument on the roof of the tractor is the N sensor, which has an oblique view angle, enabling the estimation of N status on the crop on both sides of the tractor. The yellow triangle in both photos is a depiction of the approximate field of view of the reflectance measurements.

With the aim of building estimation models for nitrogen content and yield using the Yara N-Sensor, historical data from the years 2015-2016, taken at Röbäcksdalen (63°48′N, 20°14′E) and Rådde (57°36′N, 13°15′E) were used to build estimation models for dry matter yield, crude protein (%) and total N uptake. 377 plant samples were tested in-situ in different grass and legume mixtures (6 grass species and 2 clover species) across two years, two locations and five N rates. Two mathematical methods, namely partial least squares (PLS) and support vector machine (SVM) were used to build prediction models for dry matter yield, crude protein (%) and total N uptake. Results showed that the MAE (mean absolute error) of PLS and SVM for N uptake estimation were 17 and 9.2 kg/ha, respectively (Fig. 3). The MAEs of PLS and SVM for dry matter yield estimation were 587 and 283 kg/ha, respectively. The MAEs of PLS and

SVM for crude protein estimation were 2.8 and 1.8%, respectively. The high performance of SVM to estimate N uptake and dry matter yield could provide support for varying management decisions including fertilization and timing of harvest.

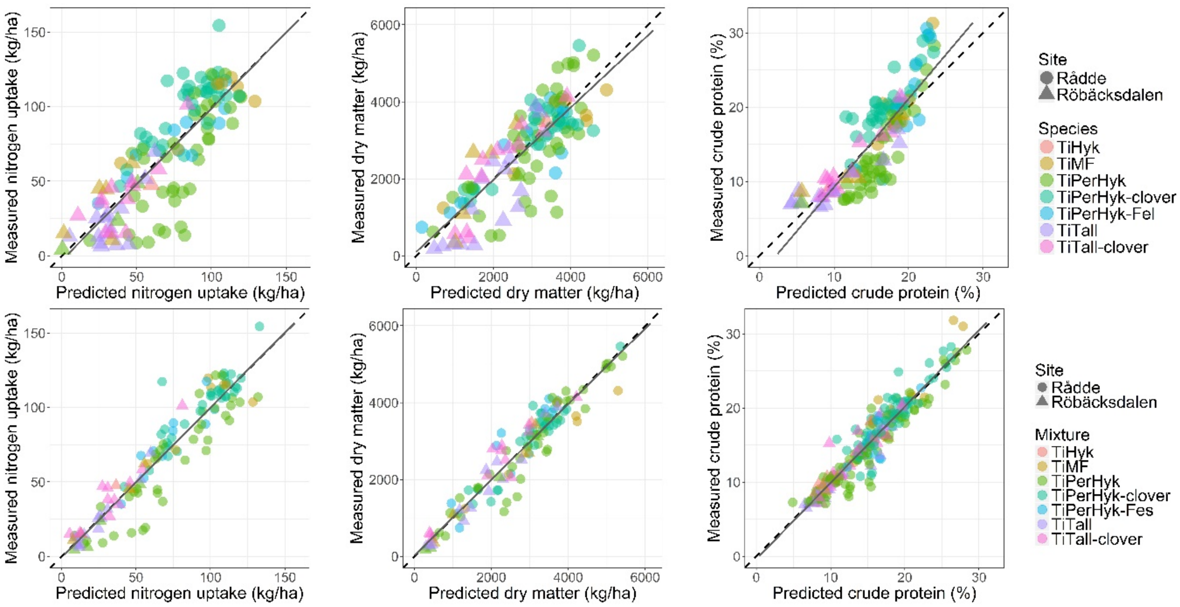

Fig. 3. Validation of partial least squares (upper graphs) and support vector machine (lower graphs) models for nitrogen uptake, dry matter yield and crude protein concentration using data from all harvests. Abbreviations for species mixtures are described in (Zhou et al., 2019).

Table 1
Calibration and validation statistics of the prediction of TDM (total dry matter yield), IVTD (in vitro true digestibility), NDF (Neutral detergent fibre), NDFD (NDF digestibility), ADF (Acid detergent fibre), ADL (Acid detergent lignin), CP (crude protein concentration), Ash, CPY (crude protein yield per area) and BC (Botanical composition) by partial least squares regression (PLS).

Variables	PLS model calibration		PLS model validation	
	RMSE	R^2	RMSE	R^2
TDM (kg/ha)	452	0.74	531	0.66
IVTD (g/kg)	19.8	0.59	20	0.57
NDF (g/kg)	43.8	0.68	45.4	0.68
NDFD (%)	2.9	0.61	3.0	0.63
ADF (g/kg)	23.3	0.56	24.3	0.56
ADL (g/kg)	6.6	0.47	8.1	0.40
CP (g/kg)	22.5	0.43	22.9	0.40
Ash (%)	0.9	0.47	0.81	0.50
CPY (kg/ha)	70.8	0.73	77.3	0.62
BC (% clover)	0.10	0.74	0.13	0.73

RMSE is root mean square error, R^2 is the coefficient of determination.

Forage quality and botanical composition estimated by hyperspectral methods

The limitation of these results from 2015-2016 is that they do not include the main forage quality variables of interest. To further evaluate the feasibility of using the Yara N-Sensor for more comprehensive estimation of forage quality we conducted detailed wet chemistry analyses for samples taken from 2017-2019. These quality variables included TDM (total dry matter yield), IVTD (in vitro true digestibility), NDF (Neutral detergent fibre), NDFD (NDF digestibility), ADF (Acid detergent fibre), ADL (Acid detergent lignin), CP (crude protein concentration), Ash, and CPY (crude protein yield per area). We then modelled the Yara N-Sensor spectral data with yield and quality variables by partial least square (PLS) regression, to estimate quality, yield, and botanical composition (percentage of clover).

The performances of the PLS models were assessed by statistical metrics (Table 1), and selected models are presented in graphical form (Fig.4). According to the results of PLS models, most variables were well estimated by the Yara N-Sensor, except for ADL, CP and Ash. The most interesting findings came from the results of botanical composition, which was most well estimated among all the evaluated variables. The range of BC values was very wide (from 0 to 90%) and samples varied across years and sites. This implies that this method could potentially provide useful information on BC, which could provide valuable information for ley management.

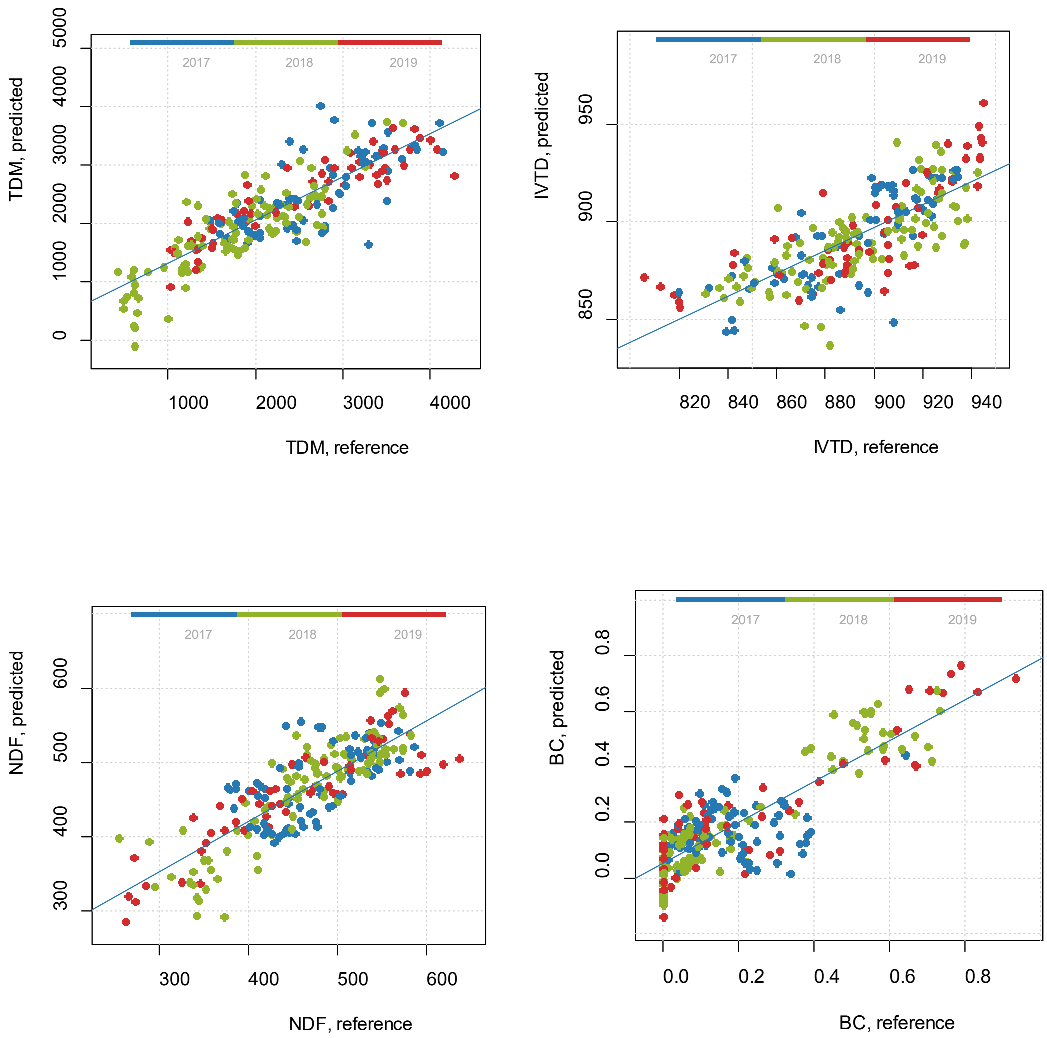

Fig. 4. Calibration of partial least squares models for TDM (total dry matter yield), IVTD (in vitro true digestibility), NDF (Neutral detergent fibre), and BC (Botanical composition). Colours indicate different years (2017-2019). The x-axis shows measured values and y-axis shows modelled values.

Further development of hyperspectral methods

There is still some work to fully analyse this dataset: i. Further investigation of the outlying points will help to understand the results and improve the models. ii. As with the published paper, machine learning methods will be used to analyze the data, in order to build more robust and accurate models. iii. A further approach is to use forage height data from the ultrasonic sensor, as an auxiliary explanatory variable together with spectral data, to test multi-sensor methods. This may improve the estimation of forage quality, since crop height is also correlated with quality. iv. The analysis so far has only used the Yara N-Sensor data, however there is also a 2-year dataset from the FieldSpec hyperspectral radiometer, which includes additional wavelengths.

BC estimated by image analysis

To test the suitability of image analysis for clover detection (species classification) in field mixtures, a total of 347 images were used from different growth stages, sites and years (2017-2019). Images were firstly cropped to remove areas outside the edge of a hoop using Adobe Photoshop software. Images were subsequently categorized to clover, grass and black background. The manually labelled clover areas were treated as the test set for the clover fraction (on an area basis). Three deep learning methods were used to detect clover areas and calculate the clover fraction for each image. Figure 5 shows the structure of the deep learning based model DeepLab V3+. The other models included SegNet and FCN-8s. Figure 6 shows the comparison between clover fractions estimated by DL based model and the manually labelled values. All three models estimated the manually labelled clover areas very well.

In practice, the farmer is interested in botanical composition on a dry weight basis, so we also correlated the area based clover fractions with hand separated botanical composition (Fig.7). Although the results were not as strong as the correlation with the manually labelled dataset, the results shows that the method is nevertheless a good predictor of botanical composition. The relationship can still be improved, as BC is not only affected by clover fraction, but also by the relative height of both grass and clover. Thus, further analysis will include using plant height as an indicator (McRoberts et al 2016) to make the BC estimation models more robust. An addition, more investigation could focus on which models work best when the actual clover composition is within the range of 0 to 40%

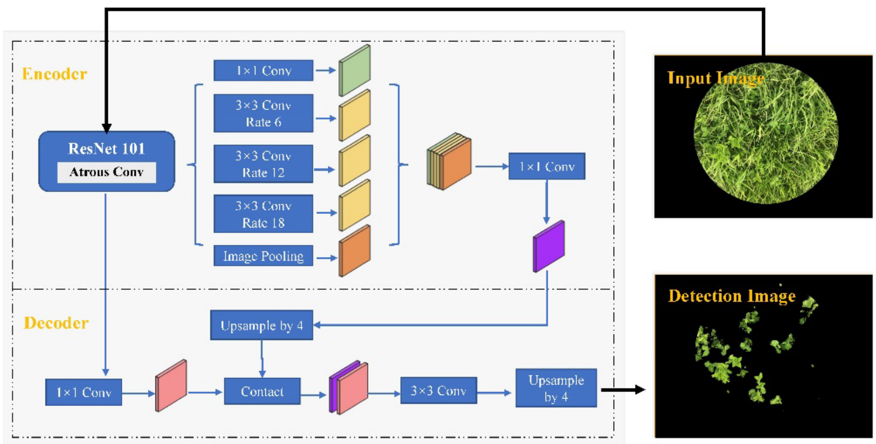

Fig. 5 Network structure of DeepLab V3+ model.

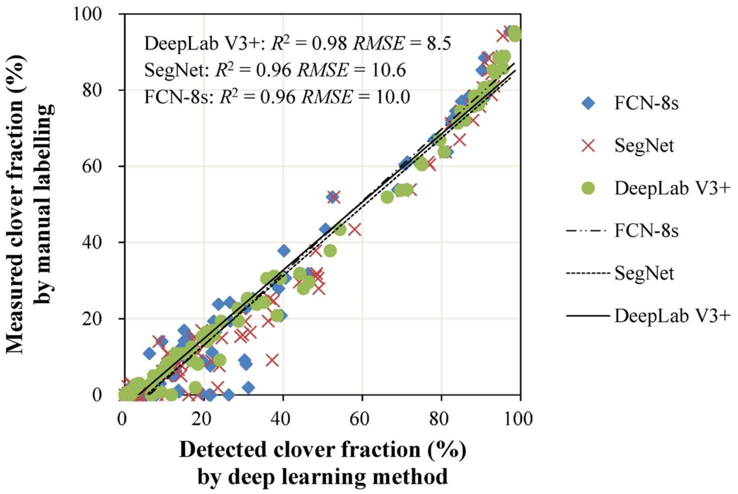

Fig. 6 Relationship between the detected (modelled) and manually labelled (measured) clover fractions using three deep learning based models.

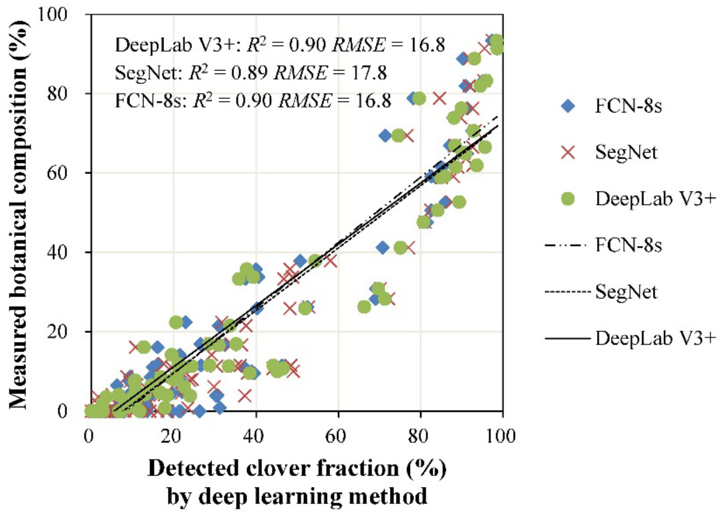

Fig. 7 Relationship between the detected (modelled) and hand separated (measured) botanical composition using three deep learning based models.

Summary

Average grass height was well estimated by using an ultrasonic sensor, which is cheap to purchase and could be installed on field machinery in combination with a data logger. Botanical composition, particularly the clover fraction, is very important for assessment of leys to determine nitrogen fertiliser rates, estimation of forage quality, and whether leys should be considered for re-sowing. This project identified two methods that have potential for practical estimation of botanical composition. Image analysis can satisfactorily estimate BC, and this could be used in conjunction with a smart phone, for assessing a single area in a field, which is useful for helping people to improve their skill at estimating BC. However, if this method was to be applied to assess BC in a whole field an automated system would need to be used, like the recently-developed clovercam system (Skovsen et al. 2019), or alternatively using a UAV, however a more expensive high resolution camera is needed in such a case. The Yara N-Sensor was also useful for estimating botanical composition, and further testing of this method is recommended. The Yara N-Sensor can also be used to estimate forage quality, however this needs more testing to identify outliers and develop models that work well across sites, years, and harvests.

Benefit to agricultural industry and recommendations

- The Yara N-Sensor has the potential to be used at harvest to estimate the botanical composition of leys. This can be used to a) provide information about clover in the harvested forage, and b) help develop recommendations for appropriate fertiliser rates, either with an average field rate or by developing botanical composition maps.
- The Yara N-Sensor can also be used to estimate the digestibility of harvested forage; however, this requires further development using machine learning methods. This is an area that the project team has identified to warrant further research.
- Image analysis methods are a promising way for determining botanical composition. This could be done using normal photos from a smartphone, or by using more sophisticated equipment mounted on machinery or UAVs.

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Zhou, Z., Parsons, D. (2018). Estimation of legume-grass swards quality with mixed remote sensing methods in Northern Sweden. Grassland Science in Europe. Cork, Ireland.

Zhou, Z., Morel, J., Parsons, D., Kucheryavskiy, S. V., & Gustavsson, A. (2019). Estimation of yield and quality of legume and grass mixtures using partial least squares and support vector machine analysis of spectral data. Computers and Electronics in Agriculture, 246-253.

Del 3: Resultatförmedling

Ange resultatförmedling av projektet, inklusive titel, referens, datum, författare/talare, och länk till presentation eller publikation om tillämpligt. Planerade publiceringar (med preliminära titlar) ska ingå i tabellen. Ytterligare rader kan läggas till i tabellen.

Vetenskapliga publiceringar	Zhou, Z., Morel, J., Parsons, D., Kucheryavskiy, S. V., & Gustavsson, A. (2019). Estimation of yield and quality of legume and grass mixtures using partial least squares and support vector machine analysis of spectral data. Computers and Electronics in Agriculture, 246-253.
	Sun, S., Liang, N., Wang, Z., Zhou, Z., Morel, J., Parsons, D. (2020). Estimation of botanical composition in mixed clover-grass fields using machine learning-based image analysis. (Under submission)
Övriga publiceringar	Planned scientific paper: Estimation of botanical composition using the Yara N-Sensor field spectrometer
	Planned scientific paper: Estimation of forage quality using the Yara N-Sensor field spectrometer
	Planned scientific paper: Estimation of forage quality using the FieldSpec field spectrometer
Muntlig kommunikation	Zhou, Z., Parsons, D. (2018). Estimation of legume-grass swards quality with mixed remote sensing methods in Northern Sweden. Grassland Science in Europe. Cork, Ireland
	Morel, J., Zhou, Z., Gustavsson, A-M., Parsons, D. (2020). Uppskattning av botanisk sammansättning med hjälp av Yara N-sensor. Vallkonferens 2020. Inst. för växtproduktionsekologi, SLU, Rapport nr 30, 38-40.
	Parsons, D., Zhou, Z., Morel, J. (2020). Mätning av foderkvalitet med fältspektrometern Yara N-sensor. Vallkonferens 2020. Inst. för växtproduktionsekologi, SLU, Rapport nr 30, 34-37.
Studentarbete	**None**
Övrigt	