SPATIAL-TEMPORAL MANAGEMENT ZONES FOR BIOMASS MOISTURE

S. Fountas

Department of Agricultural Sciences
University of Thessaly
Volos, Greece

D.D. Bochtis, C.G. Sørensen, O. Green

Department of Biosystems Engineering
Aarhus University
Tjele, Denmark

T. Bartzanas

Institute of Technology and Management of Agriculture Ecosystems,
Centre for Research and Technology-Thessaly
Volos, Greece

R.N. Jøgersen

Institute of Chemical Eng., Biotechnology and Environmental
University of Southern Denmark,
Odense, Denmark

ABSTRACT

Biomass handling operations are critical operations within the agricultural production system since they constitute the first link in the biomass supply chain, a fact of substantial importance considering the increasingly involvement of biomass in bio-refinery and bio-energy procedures. Nevertheless, the inherent uncertainty, imposed by the interaction between environmental, biological, and machinery factors, makes the available scheduling and planning tools for field operations, inadequate to deal in a efficient way with sequential tasks executed in an open and un-controlled environment. The objective of this paper was to investigate the potential of selective biomass harvesting based on biomass moisture content. A field experiment was conducted in the University farm of Aarhus University in Denmark in 2009. About 450 georeferenced biomass samples were collected when the forage was cut and left in the ground. The samples were weighed and dried and then weighed again, thereby determining the water content in the specific sample. For the prediction of the time-evolution of biomass moisture content as a function of the local weather forecast information a model based on Fluid Computational Dynamics (CFD), was developed. The use of a CFD model provides for the consideration of factors such as field topology, geometrical features and local weather conditions. Based on this model the data

were produced for a 12-hour interval and the biomass moisture maps were created. The results demonstrated specific spatial patterns for the biomass moisture which could lead to selective biomass harvesting or collection. As the time was progressing the biomass moisture maps were maintained the patterns even with a low variability within the specific field. This may also lead to the development of a decision support tool that may assist the farmers for the best timing of collecting the biomass. Further step on the system is the implementation of on-machine sensor systems for real-time measuring of the (cut) biomass quantity and moisture content, as the basis for the creation of biomass and moisture content maps depicting their spatial variability, as the basis for the development of a Decision Support System for the time-schedule of the execution of the harvesting, raking, and collecting field operations.

Keywords: CFD model, grass, moisture maps, forage harvesting

INTRODUCTION

Biomass feedstocks originates from many sources and can be converted into many different end products ranging from feeding purposes to bioenergy purposes (e.g. Bekkering et al., 2010). In terms of planning and optimization of the supply chain, it is vital that the interactions between quantity and quality parameters like moisture contents, dry matter losses in storage, and biomass bulk densities are recognized as significantly affecting the overall viability of the supply chain (Mitchell, 2000; McKendry, 2002). Biomass assessment is especially important in the case of optimized storage and for conservation purposes. Optimal scheduling system of the involved operations in a contractor-level could provide multiple benefits. The biomass handling operations scheduling (mowing, conditioning, raking, baling and collecting) is strongly subject to temporal constraints which are given by arbitrary minimum and maximum time lags between starting and completion times of any two operations (Basnet *et al.*, 2006). The presence of a minimum time lag for a given operation implies that the operation cannot start before a specified time has elapsed and after the finish of one of its predecessor operations, while the presence of a maximum time lag for a given operation implies that an operation must be started, at the latest, a certain number of time periods after the finish of one of its predecessor operations. The duration of each of these time lags is determined mainly by the physical properties (i.e. moisture content) of the cut biomass and consequently, the problem that is faced by all scheduling methods for the biomass handling operations is that the value of the mentioned time lags are known with high uncertainty. A prediction system based on the described principles, is expected to reduce this uncertainty in a high extend increasing the effectiveness of the developed scheduling models and the implemented optimisation algorithms (Bochtis and Sørensen, 2009; Bochtis and Sørensen, 2010).

Unfortunately, field drying is a complex biophysical process involving water retaining properties of the grass, energy absorption and utilization and removal of vapour from the swath (Bosma and Gabriels, 1992). To develop detailed recommendations for cutting and wilting of grass silage crops based on forecasts of meteorological conditions over a period of several days, accurate drying models are required.

Although much of the research into grass drying rates has involved experimental work carried out in the field, specific studies involved wind tunnels or drying chambers as ways of collection relevant grass drying data (Lamond and Graham, 1993; Lamond *et al.* 1989). Even so, there is a lack of information concerning the distribution of moisture either along the height of the grass or in the whole multi-hectare field. Existing models are able to estimate a single-point moisture content, or in some cases in two different vertical layers, but the models cannot predict the variability of the moisture content in the whole field. Numerical modelling techniques such as Computational Fluid Dynamics (CFD) can offer an effective way of accurately quantifying the moisture content and other environment parameters of interest under various design and weather conditions within a virtual environment. CFD is a simulation method that can efficiently estimate both spatial and temporal field fluid pressure as well as temperature and velocity, and the method has proven its effectiveness in system design and optimization within the chemical, aerospace, and hydrodynamic industries (*e.g.* Zhang *et al.*, 2006). The ubiquitous nature of fluids and their influence on system performance has caused a widespread take-up of CFD by many other disciplines. As a developing science, CFD has received extensive attention throughout the international community since the advent of the digital computer. As a result, CFD has become an integral part of the engineering design and analysis environment of many companies because of its ability to predict the performance of new designs or processes prior to manufacturing or implementation (Schaldach *et al.*, 2000). Typical applications of the CFD in the agri-food industry includes food storage, drying and sterilization (Chourasia & Goswami, 2007; van Mourik *et al.* 2009; Le Page *et al.* 2009), specific agricultural applications such as the estimation of losses of pesticide drift from field crop sprayer (Nuyttens *et al.* 2009), environmental control of agriculture buildings (Bartzanas *et al.* 2002; Sun *et al.* 2002; Bartzanas *et al.* 2004; Lee *et al.* 2005; Gebremedhin and Wu 2005; Fatnassi *et al.* 2006; Bartzanas *et al.* 2007; Molina *et al.* 2009).

The application of precision agriculture in forage grass has not seen the development as the rest of extensive crops, such as arable crops and vineyards. The main reason may be that the forage harvesters have still not reached the real applications but are mainly at research stage. Ehlert (2002) have evaluated the forage harvesters available and made significant recommendations for improvements, while Jordan et al. (2003) proposed the optimal sampling method for estimating forage grass and sward nutrients manually taken samples from the cut grass. McCormick et al. (2009) investigated the potential of site-specific application of Phosphorus in a permanent grassland with very positive findings, while Marques da Silva (2008) showed a high spatial and temporal variability in a pasture and explained the cause of this variability based on topography.

A potential decision making tool based on the approach should also consider the case where the farmer has the possibility of carrying out a spreading operation. Established research has showed that mowing and subsequent spreading achieves a significant more efficient drying process than in the case of no spreading causing the feeding value and the silage quality to be significantly increased. The cut grass may be spread in a separate operation but current available movers are capable of distributing the cut grass in a swath equal to the working with of the mower (Figure 1). By spreading the cut grass all over the field area causes the grass to better breathe and the sun and wind will better be able to dry the material.

(a)   (b)

Figure 1. Cut grass in rows (a) and spreading operation (b)

The aim of the project was to investigate the potential of selective biomass harvesting based on biomass moisture content.

MATERIALS AND METHODS

Experimental Site

The field used for the trial had an area of 14.5 hectares and was located at latitude 55.864067° N and 9.800732° E at the Organic Research Centre Rugballegaard in the Aarhus University in Denmark. The soil texture of the field for the depths of 0-100 cm, based on 17 samples, showed 2,1 % soil organic matter (SOM), 17,7 % clay (<2µm), 14,7 % silt (2-20µm), 40 % fine sand (20-200µm) and 25,4 % coarse sand (>200µm). A grass-clover mixture consisting of 32% tetraploid perennial ryegrass, 50% diploid perennial ryegrass, 10% red clover and 8% white clover was used. The applied field had earlier been grown as two fields separated by a field road, which was excluded from the experimental area. Likewise, headland of eighteen meters around the field was excluded from the trial. In August 2009 about 450 georeferenced biomass samples were collected when the forage was cut and left in the ground. The samples were weighed and

dried and then weighed again, thereby determining the water content in the specific sample.

The numerical model

The commercially available CFD code Fluent® (1998) was used for this study. The domain of interest was generated and then meshed using the integrated preprocessor software of Fluent®, Gambit. The CFD technique numerically solved the Navier-Stokes equations and the mass and energy conservation equations. The standard k-ε model (Launder and Spalding, 1974) assuming isotropic turbulence was adopted to describe turbulent transport. The k-ε turbulence model is an eddy – viscosity model in which the Reynolds stresses are assumed to be proportional to the mean velocity gradients, with the constant of proportionality being the turbulent eddy viscosity. The complete set of equations of the k-ε model can be found in Mohammadi and Pironneau (1994). The cut grass in the field was simulated using the equivalent macro-porous medium approach, which refers to the combination of the porous medium approach (to model the dynamic effect of the crop cover to the flow) with a macro-model of heat and mass transfer between the grass and the surrounding air.

For the simulation needs, a complete three dimensional (3D) model was developed. The boundary conditions used for simulations are based on average values from the measurements carried out from the meteorological station and there were the same with the data used for the analytical model. The boundary conditions prescribed a null pressure gradient in the air, at the limits of the computational domain, and wall-type boundary conditions along the soil. At the inlet of the computational domain, a logarithmic inlet velocity profile (atmospheric boundary layer model) was considered (Bartzanas et al. 2004). The air velocity (at a reference height) and the air temperature are given as known values using the values of the meteorological mast.

The weather data for the simulations were extracted from a climate database developed and run by the Faculty of Agricultural Sciences at Aarhus University. The database provides scientists, farmers and other open air users with local meteorological data on a real-time basis. The latest development includes an operational interface of the system, which is being incorporated into the *PlanteInfo* system (Jensen et al., 2001). The *PlanteInfo* system is operated as a crop management system by the the Faculty of Agricultural Sciences as a crop management system. The system will allow the exchange of daily weather data, and subsequently, it will provide for the use of such data, e.g. in connection with weather prognosis. Figure 2 shows the locations of the included weather stations in the described climate database.
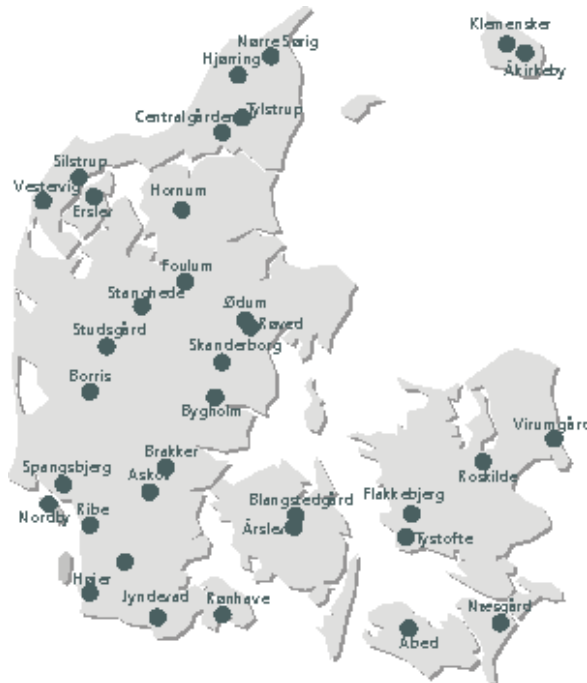
Figure 1. Location of weather stations associated with the climate database

Spatial – temporal maps

The development of biomass moisture maps was carried out using the CFD model for a 12-hour interval. The Surfer® mapping software (Golden Software Inc) was used for the development of the maps using kriging interpolating method. Descriptive statistics were carried out for all data sets.

RESULTS AND DISCUSSION

Validation of Numerical model

The climate distribution in the cut grass and more importantly, the knowledge of this distribution during the drying process is of significant importance since it can be used for better handling the cut grass (i.e tedding). Figure 3 presents the distribution of air velocity and air relative humidity, as it were evaluated with the CFD model, along the grass width in a height of 0.125 m above soil (i.e in the middle of the grass swath). The most variations were occurring close to the boundary of the grass swath where the influence of outside climate variables is strongest. However, even in the middle of the grass swath, the distribution of air velocity and air relative humidity is homogeneous. Air temperature distribution is also heterogeneous but to a smaller extend. In order to quantify the homogeneity of the air velocity, the air temperature and the air relative humidity for the tested case, the ratio of standard deviation of each parameter to its mean value was used as an indicator for homogeneity.
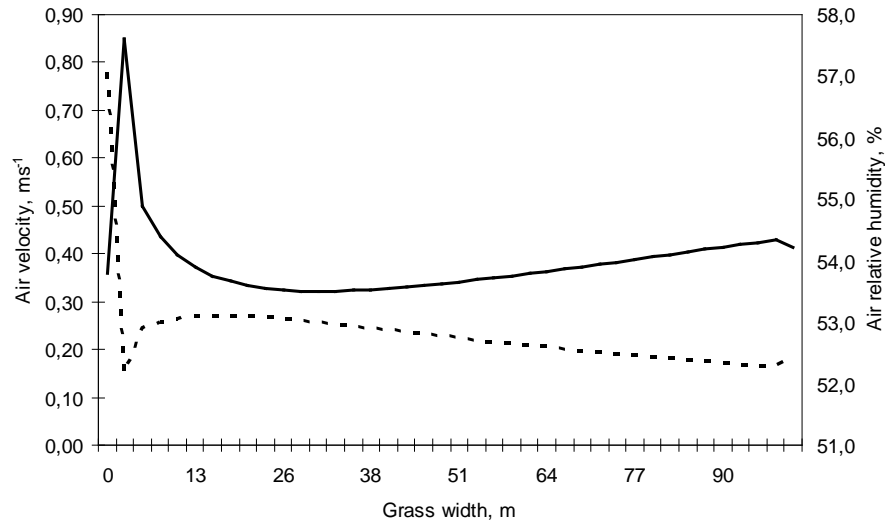
Figure 3. Distribution air velocity (- - - -) and air relative humidity (⎯⎯) along the grass width in the middle height (i.e 0.125 m from soil)

Biomass moisture maps

The CFD model was used to project the data sets for six consequent time periods with 12 hours intervals, starting from 09:00 on 22/08/2009. Table 1 presents the descriptive statistics for the six data sets. As it was expected the mean biomass moisture was reduced from 84.47% at 09:00 on 22/08/2009 to 39.79% at 21:00 on 24/08/2009. The field showed not significant variability, which was seen on the CV that varied between 15% and 29% for the six time periods.

**Table 1.** Descriptive statistics for biomass moisture data

	22/8/09 09:00	22/8/09 21:00	23/8/09 09:00	23/8/09 21:00	24/8/09 09:00	24/8/09 21:00
Minimum	77.53	59.17	56.47	46.07	44.55	37.72
Median	84.75	65.82	62.60	50.10	48.14	39.76
Maximum	90.26	74.11	70.63	56.01	53.34	42.45
Mean	84.47	65.92	62.71	50.19	48.22	39.79
Coef. of Var.	20%	29%	28%	24%	22%	15%

Figure 4 illustrates the maps for the six data sets within three days on a 12-hour interval. The values used for the classes are the minimum, mean and the maximum for each time period. This helps to visualize the variability within the field for the different time periods as the biomass moisture is decreasing throughout the time period. It is shown that biomass moisture maps showed to have similar patterns especially the three morning maps (predicted at 09:00) and the same for the evening maps (predicted at 21:00). Especially the map of 22/08/2009 at 21:00 was almost identical to the same time on 24/08/2009, even though the moisture has gone down from 66% to 38%.

The different zones that can been seen on this experimental field shows the possibility of applying the site-specific applications to collecting the cut grass to

the preferred for the storage facility biomass moisture level. Nevertheless, more work should be carried out to examine this effect in a number of fields and in more than one biomass harvest.

Further research on the system would be the implementation of on-machine sensor systems for real-time measuring of the (cut) biomass quantity and moisture content, as the basis for the creation of biomass and moisture content maps depicting their spatial variability, as the basis for the development of a Decision Support System for the time-schedule of the execution of selective harvesting, raking, and collecting field operations.
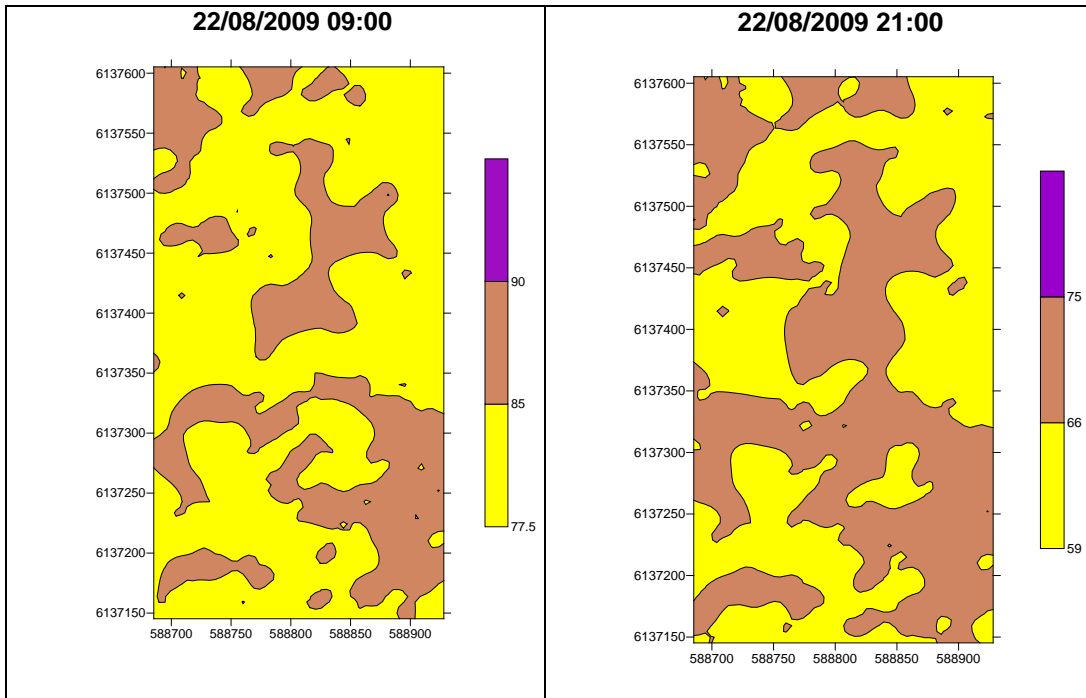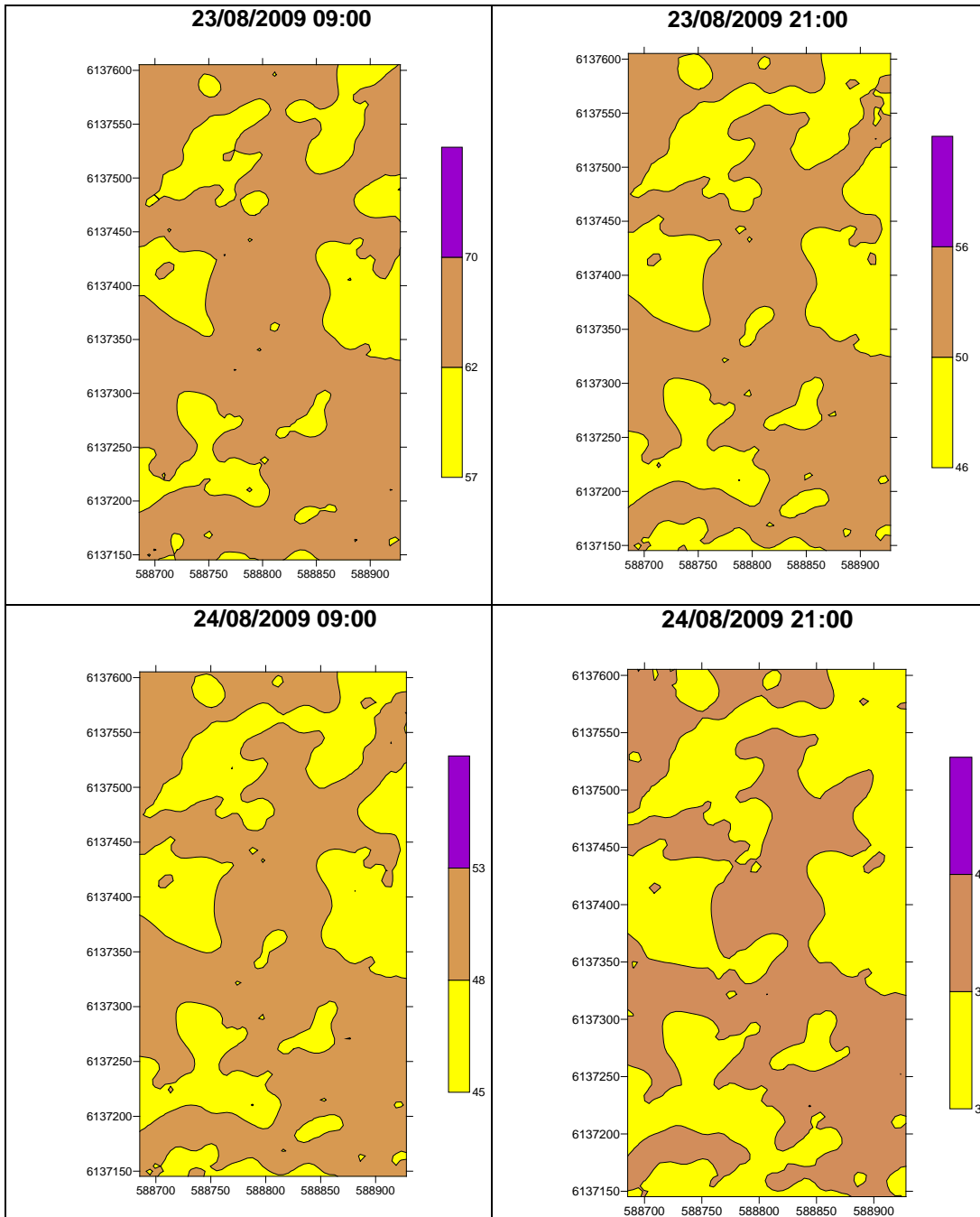
Figure 4. Biomass moisture maps

CONCLUSIONS

The main findings of this study are as follows:

- A numerical model was developed to predict the time-evolution of biomass moisture content as a function of the local weather forecast, field topology and geometrical features.

- Spatial-temporal biomass moisture maps on a 12-hour interval showed permanent spatial patterns that may lead to site-specific management on grass collection

- The implementation of on-machine sensor systems for real-time measuring of the biomass quantity and moisture content will assist in automating this process

REFERENCES

Basnet, C. B., L.R. Foulds and J.M. Wilson. 2006. Scheduling contractors' farm-to-farm crop harvesting operations. International Transactions in Operational Research, 13(1) : 1–15.

Bochtis, D.D and C.G. Sørensen. 2009.The vehicle routing problem in field logistics part I. Biosystems Engineering, 104(4) : 447-457.

Bochtis, D.D and C.G. Sørensen. 2010. The vehicle routing problem in field logistics: Part II. Biosystems Engineering, 105(2): 180-188.

Bartzanas, T., T. Boulard and C. Kittas. 2002. Numerical simulation of airflow and temperature distribution in a tunnel greenhouse equipped with an insect - proof screen on the openings. Computers and Electronics in Agriculture, 34: 207-221

Bartzanas, T., C. Kittas and T. Boulard. 2004. Effect of vent arrangement on windward ventilation of a tunnel greenhouse. Biosystems Engineering, 88 (4): 479-490.

Bartzanas, T., C. Kittas, A.A. Sapounas, and C. Nikita-Martzopoulou. 2007. Analysis of Airflow through Experimental Rural Buildings: Sensibility to Turbulence Models. Biosystems Engineering, 97 (2): 229-239

Bekkering, J., A.A. Broekhuis and W.J.T van Gemert. 2010. Optimisation of a green gas supply chain - A review. Bioresource Technology, 101 (2): 450-56

Bosma, A.H and P.C.I. Gabriels. 1992. Optimal conditions for the drying of a grass swath. In Proceedings of the 14th general meeting of the European Grassland Federation. Lathi, Finland: 153-158.

Brooker, D.B.., F.W. Bakker-Arkema and C.W. Hall. 1992. Drying and Storage of Grains and Oilseeds. Avi, Van Nostrand Reinhold, New York

Chourasia, M.K and T.K. Goswami. 2007. Simulation of Effect of Stack Dimensions and Stacking Arrangement on Cool-down Characteristics of Potato in a Cold Store by Computational Fluid Dynamics. Biosystems Engineering, 96 (4): 503-515

Fatnassi, H., T. Boulard, C. Poncet and M. Chave. 2006. Optimisation of greenhouse insect screening with computational fluid dynamics. Biosystems Engineering 93: 301–312.

Gebremedhin, K.G and B. Wu. 2005. Simulation of flow field of a ventilated and occupied animal space with different inlet and outlet conditions. Journal of Thermal Biology 30: 343–353.

Ehlert, D. 2002. Advanced Throughput Measurement in Forage Harvesters. Biosystems Engineering (2002) 83 (1), 47–53

Jordan, C., Z. Shi,, J.S. Bailey and A.J. Higgins, 2003. 3Sampling Strategies for Mapping 'Within-field' Variability in the Dry Matter Yield and Mineral Nutrient Status of Forage Grass Crops in Cool Temperate Climes. Precision Agriculture, 4 (1): 69-86.

Jensen, A.L., P.S. Boll, I. Thysen, and B.K. Pathak. 2001. Pl@nteInfo® - a web-based system for personalised decision support in crop management. *Computers and Electronics in Agriculture*. Vol. 25 (3): 271-293.

Lamond, W.J, H.B. Spencer, M.R. Graham and A.B. Moore. 1989. Effect of thin layer drying rate and swath architecture on the rate of grass swath drying under controlled conditions. Journal of Agricultural Science, Cambridge, 113: 59-65.

Lamond, W.J and R. Graham. 1993. The relationship between the equilibrium moisture content of grass mixtures and the temperature and humidity of the air. Journal of Agricultural Engineering Research, 56: 327-335.

Launder, B.E. and D.B. Spaiding. 1974. The numerical computation of turbulent flows. Computer Methods in Applied Mechanics and Engineering, 3: 269-289

Le Page, J.F., C. Chevarin, A. Kondjoyan, J.D. Daudin and P.S. Mirade. 2009. Development of an approximate empirical-CFD model estimating coupled heat and water transfers of stacked food products placed in airflow. Journal of Food Engineering, 92 (2): 208-216

Lee, I., S. Lee, G. Kim, J. Sung, S. Sung and Y. Yoon. 2005. PIV verification of greenhouse ventilation air flows to evaluate CFD Accuracy. Transactions of the ASAE 48 (6): 2277–2288.

Marques da Silva, J. R., Z. Jose, O. Peca, Z. Joao, M. Serrano, Z. Mario, J. de Carvalho, Z. Paulo and M. Palma. 2008. Evaluation of spatial and temporal variability of pasture based on topography and the quality of the rainy season. Precision Agriculture 9: 209–229.

McCormick, S., C. Jordan and J.S. Bailey. 2009. Within and between-field spatial variation in soil phosphorus in permanent grassland. Precision Agriculture 10: 262–276

McKendry, P. 2002. Energy production from biomass (part 1): overview of biomass. Bioresource Technology, 83 (1): 37-46.

Mitchell, C.P. 2000. Development of decision support systems for bioenergy applications. Biomass and Bioenergy 18 (4): 265-78

Mohammadi, B. and O. Pironneau. 1994. Analysis pf the k-epsilon Turbulence Model. Research in Applied Mathematics, Wiley, New York, Masson, Paris.

Molina-Aiz, F.D, D.L. Valera, A.A. Peña, J.A. Gil and A. López. 2009. A study of natural ventilation in an Almería-type greenhouse with insect screens by means of tri-sonic anemometry. Biosystems Engineering, 104 (2): 224-242

Nuyttens, D., M. De Schampheleire, P. Verboven and B. Sonck. 2009. Comparison between indirect and direct spray drift assessment methods. Biosystems Engineering, *in press*, doi:10.1016/j.biosystemseng.2009.08.004

Schaldach, G., L. Berger, I. Razilov and H.Berndt. 2000. Computer simulation for fundamental studies and optimisation of ICP spray chambers. ISAS (Institute of Spectrochemistry and Applied Spectroscopy) Current Research Reports, Berlin, Germany.

Sun, H., R. Stowell, H. Keener, D. Elwell and F. Michel. 2002. Twodimensional computational fluid dynamics modelling of air velocity and ammonia distribution in a high rise hog building. Transactions of the ASAE 45: 1559–1568

van Mourik S., H. Zwart and K.J. Keesman. 2009. Integrated open loop control and design of a food storage room. Biosystems Engineering 104 (4): 493-502

Zhang, Z., H. Liu, S.P. Zhu and F. Zhao. 2006. Application of CFD in ship engineering design practice and ship hydrodynamics. Journal of Hydrodynamics, 18 (3): 315-322