Agronomy Research **17**(2), 491–498, 2019
https://doi.org/10.15159/AR.19.033

The course of drying and colour changes of alfalfa under different drying conditions

P. Kic

Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ165 21 Prague, Czech Republic
*Correspondence: kic@tf.czu.cz

Abstract. One of the conditions for successful livestock breeding and efficient livestock production is to ensure quality feed. High quality feed for livestock is alfalfa, which has a very high nutritional value and its cultivation is also important for crop production in terms of improving the soil structure and nitrogen enrichment. The aim of this paper is to inform about the experimental investigations of alfalfa drying and colour changes under different drying conditions. The results of natural convection at 27.5 °C and 40% relative air humidity are compared with forced convection at 1.2 m s^{-1} air flow velocity at the same air temperature and with results of drying by natural convection at 50 °C. The dry matter content was measured gravimetrically after drying in a hot air dryer at 105 °C. Higher drying rates shorten the time required for drying and earlier preservation and storage in the hayloft or in the hay bales. This reduces the risk of wetting of feed such by rain and degradation by fungi, etc. A shorter drying time is also important in terms of energy savings. The precise knowledge of the drying process and drying curves allows also to determine the appropriate time for storage and conservation for production of another type of fodder e.g. haylage or silage. The measurement results show a positive effect of higher drying speeds as well as increased air temperature. Higher drying air temperature during convection led to the partial lightening and greater yellowing of the feed.

Key words: forced drying, natural drying, moisture, spectrophotometer, temperature.

INTRODUCTION

Alfalfa (*Medicago sativa*) is used because of its high protein content and highly digestible fibre for cattle, horses and other domestic animals. Alfalfa is most often harvested and conserved as hay, but can also be made into haylage or silage. The differences are according to the moisture. Dry matter content (DM) is one of fundamental characteristics in conservation of alfalfa (Bebb 1990; Maloun, 2001). The DM content in fresh plants depends on the weather and on phenophases in a wide range from 11 to 25%. During the conservation it is necessary to increase the amount of DM at least to 35% (preferably 40%) for the production of silage in horizontal or tower silos.

For the production of haylage (silage with higher DM) it is necessary to increase DM content to 45% (in horizontal or tower silos), for production of round bale wrapped in foil to DM content from 45 to 65%. DM content of 75–85% allows storage of forage in round bales without using the packaging film (under shelter) or in hayloft for longer periods. In the production of uncoated hay bales it is needed to prevent mould growth by increased DM content at least to 75%.

For the production of quality hay the DM of 75–85% should be achieved, which requires drying time 2–4 days of favourable weather. High-quality alfalfa hay should be green, soft to the touch, with a high proportion of leaves, smelling well and without admixtures. Moisture level should not be higher than 15%.

Drying time and temperature together with the moisture influence the quality of the final dry fodder. There are many different applications of drying for the agricultural (Jokiniemi et al., 2012; Aboltins & Palabinskis, 2013; Jokiniemi et al., 2014) purposes. Problems of natural drying applied to drying of special plants are solved also in some scientific publications, e.g. (Aboltins & Kic, 2016).

The increased air velocity for convection or suitable material preparation can influence the drying process positively. But too high air velocity, needed to accelerate the drying process, can cause problems with losses of light particles particularly at the final stage of drying when forage has low water content and thus low density of small particles. In practice, sometimes DM is not sufficient in the production or storage of hay, haylage or silage, or on the contrary, DM is too high which can cause higher losses of fodder. DM is an important determinant of intake by animals (Pond & Pond, 2000). The attention of alfalfa drying under artificial conditions is paid in different scientific publications, e.g. (Adapa et al., 2004; Osorno & Hensel, 2012).

The aim of this work is to bring some new experimental and theoretical investigations of alfalfa drying by natural and forced convection with different air velocities compared with drying with increased temperature to 50 °C.

In recent years, great attention has been paid to the colour, as an important parameter for determination of some data in agriculture and food industry. This includes e. g. parameters relevant to determine the appropriate harvest period or properties of vegetation and plants (Hernandez & Larsen, 2013; Kross et al., 2015; Prabhakara et al., 2015; Rigon et al., 2016) and similar agro – technical or even ecological data (Tillack et al., 2014). This is mainly used by remote sensing methods.

In order to determine the quality of some agricultural products, the CIELAB colour scheme is used, where colours are expressed by L* value (lightness), redness (a* values) and yellowness (b* values), e.g. Orazem et al., 2013; Kic, 2018; Peralta et al., 2018. Since these methods are still rather difficult to access, they are used for expensive products, where colour determination can be important for consumers. The use for measurements of traditional crops, such as fodder, is not yet common.

In practice, however, some practical advice and recommendations for farmers are used on the basis of farmers' experience for centuries, e.g. hay should not be brown, dark, etc. This study therefore shows the possibility of using exact colour measurement as a parameter describing the properties of a harvested or stored feed crops such as alfalfa. It can be assumed that further research from this point of view will continue and further develop this issue.

MATERIALS AND METHODS

The laboratory measurements were carried out at the Faculty of Engineering CULS Prague during summer weather conditions in July. Three different drying conditions of alfalfa were selected for this research work.

To study the drying kinetics, alfalfa samples which were cut up into a particle length from 2 to 5 cm, were placed in a thin layer about 50 mm on sieve tray with mesh 3 x 4 mm of total area approximately 20,400 mm^2. Initial weight of each sample on the tray was approximately 60 g.

The drying conditions of first sample A were natural, with average temperature of drying air 27.5 ± 0.8 °C and relative humidity 39.9 ± 2.7% and natural convection. The forced drying of the second sample B was in drying chamber with air velocity 1.2 m s^{-1} and the same air temperature and humidity.

To study the influence of higher temperature on the drying process, the third sample C was put in the drying chamber with increased air temperature 50 °C and 0 m s^{-1} air velocity.

The moisture content in the alfalfa samples was identified by the gravimetric measurement in regular time intervals. Samples were weighed during the drying on the digital laboratory balance KERN-440-35N with maximum load weight 400 g, with resolution 0.01 g and accuracy ± 10 mg and values were recorded. Each measuring tray was weighed every 30 min. The total drying time 46 h was adapted to the need for a determination of lowest moisture content, which can be achieved by convective drying with air temperature 27.5 °C, and 21 h for drying with increased air temperature 50 °C.

Air speed was measured by anemometer CFM 8901 Master with resolution 0.01 m s^{-1} and accuracy ± 2% of final value. Air temperature and humidity was measured by the sensor FHA646-E1C connected to the data logger ALMEMO 2690-8.

The DM in alfalfa samples was identified by gravimetric measurement using an MEMERT UNB-200 air oven under temperature 105 °C. Samples were weighed on a KERN 440-35N laboratory balance in regular time intervals. The total drying time was adapted to the need for a determination of the equilibrium moisture.

The following main parameters are calculated from the measured values of all alfalfa samples. Water content, dry basis u is defined as the ratio of the mass of water m_W contained in a solid to the mass of dry basis m_S, expressed in Eq. (1):

$$u = \frac{m_W}{m_S} \quad (1)$$

where u – water content, dry basis, g g^{-1}; m_W – mass of water, g; m_S – mass of dry basis, g.

Water content, wet basis w is the ratio of the mass of water m_W contained in a solid to the mass of the moist solid $m = m_S + m_W$, expressed in Eq. (2):

$$w = \frac{m_W}{m} 100 \quad (2)$$

where w – water content, wet basis, %.

Changes of the water content du during the time difference dt describe the drying rate N expressed in Eq. (3):

$$N = \frac{\Delta u}{\Delta t} \quad (3)$$

where N – drying rate, g $g^{-1}min^{-1}$; t – time, min.

The colour was evaluated according to the CIELAB system where colour attributes lightness (L* value), redness (a* value) and yellowness (b* value) were measured five times of each fresh sample, after convection (natural or forced) drying and after hot air drying in 105 °C. The instrument used for this research, Spectrophotometer CM-600d

Konica Minolta, was first calibrated. Calibration is based on the black (L* = 0) and white (L* = 100) standards.

The obtained results of colour range coordinates of tested alfalfa samples were processed by Excel software and verified by statistical software Statistica 12 *(ANOVA* and *TUKEY HSD Test*) to recognise if the differences are significant. Different superscript letters (*a, b*) in common are significantly different from each other in the columns of the tables *(ANOVA; Tukey HSD Test;* $P \le 0.05$*)*, e.g. if there are the same superscript letters in the columns (before drying, after natural drying and after drying in oven) it means the differences between the values of the same homogenous group are not statistically significant at the significance level of *0.05*.

RESULTS AND DISCUSSION

The kinetics of alfalfa drying process of A, B and C samples described by the curves calculated according to equations (1), (2) and (3) is in Figs 1–5. The whole convection drying time 46 h was sufficient to the maximal drop of water content which can be achieved by convection with air temperature 27.5 °C and relative humidity 39.9%.

The curves of water content, dry basis u (g g^{-1}) in Fig. 1 show that the increased air velocity to 1.2 m s^{-1} (sample B) in comparison with natural convection (sample A) reduced the time of drying considerably. The biggest drop of water content and shortest time for drying (only 21 h) is in the case of sample C, which has been caused by the increased air temperature to 50 °C.

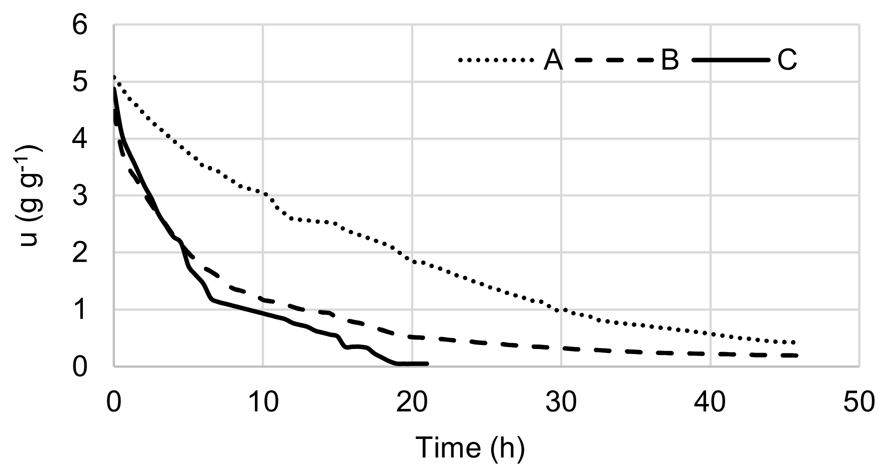

Figure 1. Water content, dry basis u (g g^{-1}) of all 3 alfalfa samples during the drying process.

The course of water content, wet basis w (%) during the drying is presented in Fig. 2. The decrease of water content, wet basis is significantly slower in the case of natural convection (sample A) than with forced convection (sample B). The water content, wet basis achieved by convection drying was 29.57% in the case of natural convection (sample A), 16.11% in the case of forced convection (sample B). The fastest drop of water content, wet basis and the lowest reached water content, wet basis (w = 4.5%) was in the case of drying by air at 50 °C (sample C).

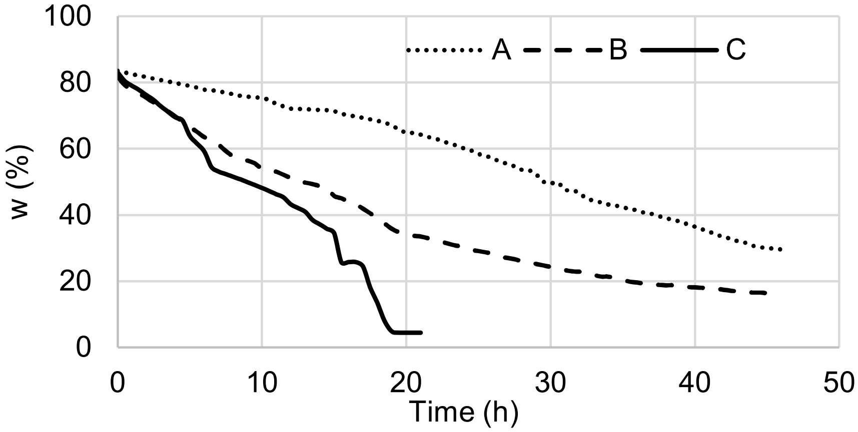

Figure 2. Water content, wet basis w (%) of all 3 alfalfa samples during the drying process.

The course of drying rate N (g $g^{-1}min^{-1}$) during 46 h of drying is presented in Fig. 3. To see better differences influenced by different drying conditions, drying rates from the first 10 hours are presented in Fig. 4.

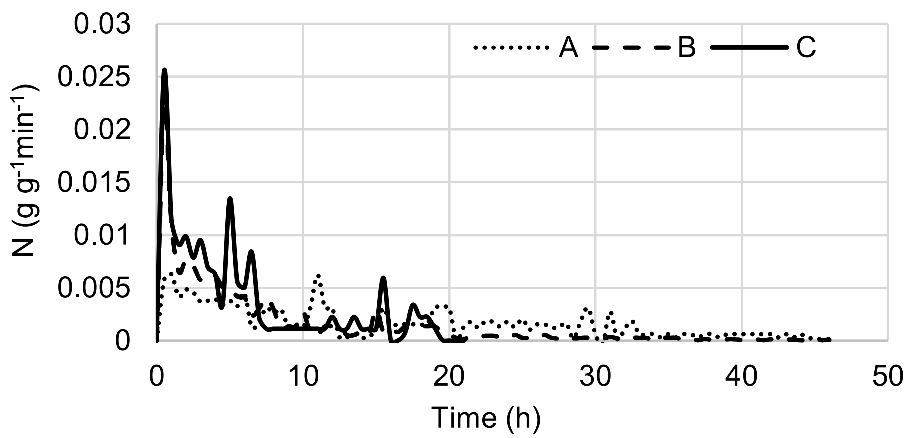

Figure 3. Drying rate N (g $g^{-1}min^{-1}$) of 3 alfalfa samples during 46 h of drying.

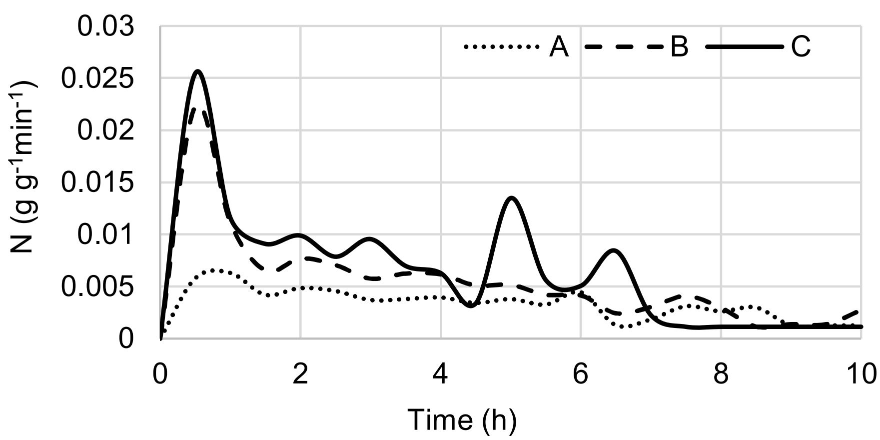

Figure 4. Drying rate N (g $g^{-1}min^{-1}$) of 3 alfalfa samples during the first 10 h of drying.

The biggest drying rates N ($g\ g^{-1}min^{-1}$) were achieved during the first 30 min. According to Fig. 4 the difference between the sample B and C is not significant during that time. This can be explained by the evaporation of the first portion of moisture from the surface parts of the plants. The drying rate of sample A by natural convection is significantly smaller than the sample B and C during the first 7 hours.

Rather interesting is the dependence of drying rate N ($g\ g^{-1}min^{-1}$) on the water content, dry basis ($g\ g^{-1}$) presented in Fig. 5, describing both very important parameters of drying process. The best relation between the drying rate and water content is achieved if the water content is high and with increased temperature (sample C) or higher air velocity of forced drying (sample B). There is a big difference between the drying with air velocities 1.2 $m\ s^{-1}$ (sample B) and natural convection (sample A). The increased air velocity has positive impact on the whole process of drying.

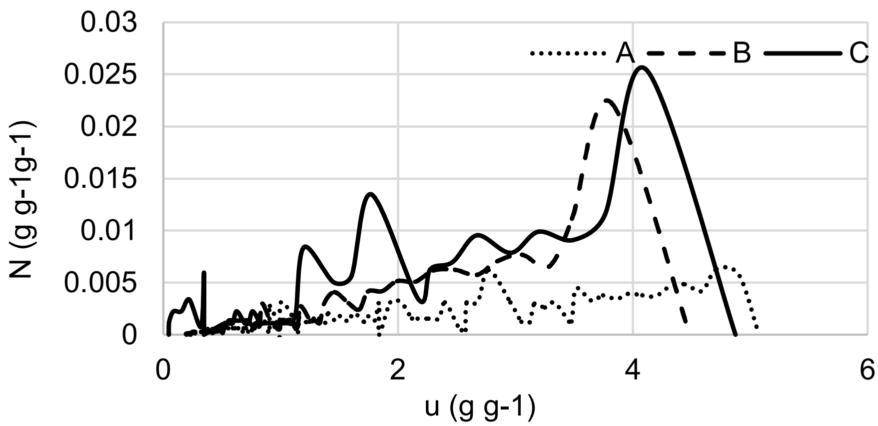

Figure 5. Drying rate N ($g\ g^{-1}min^{-1}$) of 3 alfalfa samples as a function of water content u ($g\ g^{-1}$) during the drying process.

The mean values and standard deviations (SD) calculated from the results of measurements of the lightness L* are presented in the Table 1. There are also included in the Table 1 the colour specification a* and b* mean values with SD.

The results of lightness L* in the Table 1 indicate that the measured samples were slightly lighten by all types of drying process, which is statistically significant. The smallest change of lightness ($\Delta L^* = 2.58$) was in the case of the sample C from $L^* = 37.49 \pm 0.30$ after drying with a higher air temperature of 50 °C to $L^* = 40.07 \pm 1.29$. The smallest change of lightness ($\Delta L^* = 0.59$) was also in this case after the subsequent hot air drying at 105 °C oven.

The biggest increase of lightness ($\Delta L^* = 5.91$) was in the case of sample B. Lightness increased from $L^* = 35.80 \pm 0.94$ due to the natural drying by increased air flow velocity to lightness ($L^* = 41.71 \pm 2.80$). However, the following hot air drying by 105 °C did not cause such a high change of lightness.

There are recognised also changes in colour shades, a* and b*. The greenness (-a*) of all samples was only slightly reduced by the drying process, which was not in any case statistically significant. The yellowness (b*) was increased. Statistically significant increase of yellowness was in the case of natural drying A and in the case of hot air drying samples C by 50 °C; the yellowness was increased from $b^* = 13.41 \pm 0.46$ to the value of $b^* = 20.47 \pm 0.55$, which causes the difference $\Delta b^* = 7.06$.

Table 1. Colour range coordinates (L*, a* and b* mean values with SD) of tested alfalfa samples. Different letters (*a, b, c*) in the superscript are the sign of high significant difference (*ANOVA; Tukey HSD Test; $P \leq 0.05$*)

State of the measured alfalfa samples A, B, C	Parameter Drying conditions	L* ± SD	a *± SD	b* ± SD
Sample A before natural drying	t = 27.5 °C, natural conv.	38.70 ± 4.58^{a}	-9.04 ± 0.46^{a}	15.72 ± 2.77^{a}
Sample A after natural drying	t = 27.5 °C, natural conv.	$42.28 \pm 1.86^{a,\,b}$	-8.60 ± 0.44^{a}	$19.55 \pm 1.39^{a,\,b}$
Sample A after drying in oven	t = 105 °C, natural conv.	48.81 ± 0.87^{b}	-8.61 ± 0.45^{a}	24.20 ± 2.53^{b}
Sample B before forced drying	t = 27.5 °C, natural conv.	35.80 ± 0.94^{a}	-9.01 ± 0.5^{a}	14.66 ± 1.99^{a}
Sample B after forced drying	t = 27.5 °C, v = 1.2 m s^{-1}	41.71 ± 2.80^{b}	-8.84 ± 0.92^{a}	18.98 ± 3.23^{a}
Sample B after drying in oven	t = 105 °C, natural conv.	$39.77 \pm 3.31^{a,\,b}$	-8.51 ± 0.07^{a}	18.87 ± 1.23^{a}
Sample C before natural hot air drying	t = 27.5 °C, natural conv.	37.49 ± 0.30^{a}	-8.93 ± 0.22^{a}	13.41 ± 0.46^{a}
Sample C after natural hot air drying	t = 50 °C, natural conv.	40.07 ± 1.29^{b}	-8.52 ± 0.50^{a}	20.47 ± 0.55^{b}
Sample C after drying in oven	t = 105 °C, natural conv.	40.66 ± 0.84^{b}	-8.98 ± 1.75^{a}	19.70 ± 3.02^{b}

SD – Standard deviation.

The influence of hot air drying in oven (105 °C) after the natural or forced drying did not cause significant changes of lightness or greenness or yellowness. The greatest change of lightness due to hot-air drying at 105 °C (ΔL * = 6.53) was in the case of sample A, but this small changes are not statistically significant.

CONCLUSIONS

This research is useful for verification of the influence of different air parameters on the drying process of alfalfa. In order to achieve the suitable water content of alfalfa for different conservation applications with economic benefits, the optimization of drying time should be provided and respected.

It has been found that the increased temperature and forced convection has a strong and positive influence on drying time in comparison with free drying by natural convection. There are big differences between the results of drying with air velocities 0 m s^{-1} and 1.2 m s^{-1}, nevertheless more progressive results in this research were achieved by the increased temperature to 50 °C. Future research in this area, partly described and expressed by drying coefficient, should be focused on the study of other factors influencing the drying process especially by different air temperatures.

Measured changes of colours during the drying process create the background for further research on this field. The results of lightness L* indicate that the measured samples were slightly lighten after the drying process. Drying alfalfa by air with temperature 50 °C increased yellowness.

Changes of colours are important parameters describing the changes of crops quality which should be studied also for other levels of drying conditions and also for other types of materials. New information about these properties should be respected during the harvest and storage of agricultural products.

REFERENCES

Aboltins, A. & Palabinskis, J. 2013. New types of air heating solar collectors and their use in drying agricultural products. *Agronomy Research* **11**, 267–274.

Aboltins, A. & Kic, P. 2016. Research of some medical plants drying process. In: *15th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 1145–1150.

Adapa, P.K., Schoenau, G.J. & Arinze, E.A. 2004. Fractionation of alfalfa into leaves and stemps using a three pass rotary drum dryer. *Biosystems Engineering* **91**, 455–463.

Bebb, D.L. 1990. *Mechanised livestock feeding*.BSP professional books, Oxford, 209 pp.

Hernandez, L.F. & Larsen, A.O. 2013. Visual definition of physiological maturity in sunflower (Helianthus annuus L.) is associated with receptacle quantitative color parameters. *Spanish Journal of Agricultural Research* **11**(2), 447–454.

Jokiniemi, T., Mikkola, H., Rossner, H., Talgre, L., Lauringson, E., Hovi, M. & Ahokas, J. 2012. Energy savings in plant production. *Agronomy Research* **10**, 85–96.

Jokiniemi, T., Jaakkola, S., Turunen, M. & Ahokas, J. 2014. Energy consumption in different grain preservation methods.*Agronomy Research* **12**, 81–94.

Kic, P. 2018. Mushroom drying characteristics and changes of colour. In: *17th International Scientific Conference Engineering for Rural Development*. Latvia University of Agriculture, Jelgava, pp. 432–438.

Kross, A., McNairn, H., Lapen, D., Sunohara, M. & Champagne, C. 2015. Assessment of RapidEye vegetation indices for estimation of leaf area index and biomass in corn and soybean crops. *International Journal of Applied Earth Observation and Geoinformation* **34**, 235–248.

Maloun, J. 2001. *Technological equipment and main processes in the production of fodder*. CULS, Faculty of Engineering, Prague, 201 pp. (In Czech).

Orazem, P., Mikulic-Petkovsek, M., Stampar, F. & Hudina, M. 2013. Changes during the last ripening stage in pomological and biochemical parameters of the 'Redhaven' peach cultivar grafted on different rootstocks. *Scientia Horticulturae* **160**, 326–334.

Osorno, F.L. & Hensel, O. 2012. Drying homogeneity of grass mixture components in a rotary drum. *Drying Technology* **30**, 1931–1935.

Peralta, D.V., Rodgers, J.E., Knowlton, J.L. & Fortier, C.A. 2018. Upland Cotton Surface Amino Acid and Carbohydrate Contents vs. Color Measurements. *Journal of Cotton Science* **22**, 142–152.

Pond, W.G. & Pond, K.R. 2000. *Introduction to animal science*. John Wiley & sons, inc. New York, 687 pp.

Prabhakara, K., Hively, W.D. & McCarty, G.W. 2015. Evaluating the relationship between biomass, percent groundcover and remote sensing indices across six winter cover crop fields in Maryland, United States. *International Journal of Applied Earth Observation and Geoinformation* **39**, 88–102.

Rigon, J.P.G., Capuani, S., Fernandes, D.M. & Guimarães, T.M. 2016. A novel method for the estimation of soybean chlorophyll content using a smartphone and image analysis. *Photosynthetica* **54**(4), 559–566.

Tillack, A., Clasen, A., Kleinschmit, B. & Főrster, M. 2014. Estimation of the seasonal leaf area index in an alluvial forest using high-resolution satellite-based vegetation indices. *Remote Sensing of Environment* **141**, 52–63.