Animal Science Journal

Animal Science Journal (2012) **83,** 350–357 doi: 10.1111/j.1740-0929.2011.00961.x

ORIGINAL ARTICLE

Effects of moisture content in quail litter on the physical characteristics after pelleting using a Siriwan Model machine

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ABSTRACT

Quail litter (QL), a combination of accumulated quail manures, feathers, spilled feed and bedding materials, is a potential plant fertilizer, ruminant feed ingredient and other value-added applications. In general, utilization of this litter has been limited to within a few kilometers of quail farms, because it has low density. Pelleting is one possible way to enhance storage, transportation and off-site utilization. The purposes of this study were to show the procedures of pelleting and determine the effects of moisture content in fresh QL on the values of physical characteristics. Results obtained showed that bulk and particle densities of QL pellets decreased and increased, respectively, with an increase in moisture content. Porosity, durability, rupture force and decomposition were also affected by moisture content. Pelleting increased the bulk density of QL. Thus, this method more economically transported the litter from the quail farm to distant areas.

Key words: *bedding material, density, estimation, moisture, pellet quality.*

INTRODUCTION

The Japanese quail (*Coturnix japonica*) is an excellent bird for commercial domestication because of its rapid growth, high laying, fecundity and environmental resistance as compared to chickens (Iwamoto *et al*. 2008). In Thailand, Japanese quail production has undergone steady growth all over the country during the past 20 years and the production of quail eggs and meat is expected to further increase in response to an increase in domestic consumption and export (Suppadit 2009a). The total census of quail in 2009 was about 5.2 million (Department of Livestock Development 2010), which resulted in an estimated annual production of 3600–3700 tonnes of fresh quail litter (QL) (1000 birds produce 0.704 tonnes of litter in raising between the starter stage and a maturity stage) (Suppadit 2009a). QL refers to the combination of accumulated manures, feathers, spilled feed and bedding materials, which is rice (*Oryza sativa* L.) hulls (Suppadit *et al*. 2009). The high organic matter and nutrient content that it holds, along with the positive effects of its applications on soil texture, have encouraged its exploitation on agricultural soils (Lopez-Mosquera *et al*. 2007; Bernhart & Fasina 2008; Suppadit *et al*. 2008a) since it not only improves soil fertility and aeration, but also increases the water-holding capacity of the soil (Gupta & Gardner 2005; Suppadit *et al*. 2008b). In addition, the litter is known as a feed ingredient source for ruminants (Jackson *et al*. 2006; Suppadit *et al*. 2008a), because ruminants can metabolize it into essential amino acids for growth and maintenance (Suppadit 2005).

Unfortunately, quail production is often concentrated within a small area in Thailand, especially in the central zone (e.g. Angthong, Ayudhya, Lopburi, Phichit, Saraburi, Singburi and Suphanburi). This zone accounts for approximately 86.0% of the total quail production and generates nearly 3100 tonnes of litter annually (Suppadit 2009a). The result is that disposal of a large amount of the litter is also confined to relatively small areas. The cost of transporting low-density QL from the generation site to the place of use has in addition limited the practical utilization of the litter to within a few kilometers of quail farms. This

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Received 23 February 2011; accepted for publication 12 May 2011.

has resulted in a build-up of N and P in the soil on this land (Kingery *et al*. 1994; McMullen *et al*. 2005). Ground water and surface water problems have also been created as excess nutrients run off the land or leach into ground water supplies (Wood *et al*. 1999; McMullen *et al*. 2005). There is, therefore, the need to be able to economically transport the litter from the farm of production to areas where it can be effectively used as fertilizer and for other value-added uses such as feed ingredient.

A promising approach for reducing these problems or restrictions of fresh QL is a pelleting method (Suppadit & Panomsri 2010). This technique may help to obtain a readily stored product that neither leaches nor has dust, increasing its environmental acceptability and financial value (Suppadit *et al*. 2008c). The prototype pelleting machine called 'Siriwan Model' was invented in 1997 by the correspondence author (Tawadchai Suppadit), and its commercial production was rolled out in 1998. Later, this model machine was modified in 2008 in order to increase productivity capacity (Suppadit & Panomsri 2010). It is this machine hoped this machine would contribute to optimizing QL efficiency in terms of storage, transportation cost and off-site utilization. Therefore, the physical characteristics of the QL pellets, such as bulb density, particle density, porosity, durability, rupture force and decomposition, need to be measured in order to quantify the integrity of the pellets. The purposes of this article were to show the procedures of the QL pelleting machine and investigate the effects of moisture content in fresh QL on the values of the above characteristics because moisture is the key factor that affects many aspects of the pelleting process (Suppadit & Panomsri 2010).

MATERIALS AND METHODS

Sample preparation of fresh QL

The sampling time of fresh QL was June to September 2010. Forty samples of fresh QL were obtained from the Siriwan Co. Ltd.'s network of Japanese quail houses, in the central zone of Thailand, consisting of concrete-floored and open houses with a stocking density of 50.0 birds/m^2. At the starter to maturity stages with unsorted sex of each 30-day quail-raising cycle, the floor was covered with 5.00–5.50 kg/m^2 of rice (*Oryza sativa* L.) hull, the by-product of rice-growing that is widely used for quail farming in Thailand (Suppadit 2009a). At the end of each raising cycle, after removal of the birds, 50 kg per each sample was immediately collected from each house.

Moisture content determination

Moisture content (MC; %) measurement was made by placing 10 g of each sample in an air convection oven set at 105 ± 3°C for 48 h according to ASAE Standard S269.4 (ASAE 2002). The moisture content was calculated using the following equation:

$$MC = 100\,(m_p - m_s)/m_p$$

where m_p = primary mass of sample (g) and m_s = secondary mass of sample (g).

Pelleting

The pelleting technique of the Siriwan Model machine is to mold QL into a pellet form that produces cylindrical pellets 6 mm in diameter and 1.5–2.0 cm in length. The machine is a roller-and-die pellet press which is a roller-ring die type. This type has a basic structure of one die with many holes and three rollers.

This pelleting followed Suppadit and Panomsri's (2010) processes. Each fresh QL sample (Fig. 1a) is sent into a screw conveyer (Fig. 1b) and moved into a receiving elevator (Fig. 1c), then into the pelleting chamber (Fig. 1d,e). The QL is fed between the die (35 mm die thickness) (Fig. 1f) and rollers (Fig. 1g), and as the rollers turn, the QL is forced into the holes, producing the pellets. The machine uses a truck engine (Fig. 1h) to drive the roller axis. The processing speed is adjustable (Fig. 1i) as the machine is fitted with a gearbox adjustable between 140 and 160 rounds per min (rpm) (Fig. 1j). The rollers' movement and die during the compression process generates heat of 90–95°C measured in the QL pellet after releasing from the die. The temperature can be controlled by adjusting the pressure. The pelleted QL is cut with blades and the length is adjustable, depending on requirement (Fig. 1k). The pelleted QL is carried through a rail conveyer to store in a bin to cool down before sampling (Fig. 1l). After cooling, each pelleted QL sample is collected into plastic bags (Fig. 1m,n) to analyze physical characteristics at the laboratories of The Thailand Institute of Scientific and Technological Research, Pathumthani and Chiang Mai Field Crop Research Center, Chiang Mai, Thailand.

Physical characteristics

Bulk density

The bulk density (ρ_b; kg/m^3) of each sample pellet was determined by means of a bulk density measurement apparatus (Burrows Co., Evanston, IL, USA), according to modified ASAE Standard, S269.4 (ASAE 2002). This procedure involves filling the container of the apparatus (947 mm^3) via a funnel that is at a height of 40 mm above the top edge of the container and tapping the container several times before mass measurements. Bulk density was taken as the ratio of the mass sample in the container to the volume of the container (Fasina 2008).

Particle density

The particle density (ρ_ρ; kg/m^3) of each sample pellet was computed according to the McMullen *et al.* (2005) method using the following equation:

$$\rho_\rho = m_\rho / v_\rho$$

where m_ρ = mass of pellets (kg) and v_ρ = pellet volume (m^3).

The volume of the pellets was obtained by means of a gas (helium) displacement pycnometer (Model Accupyc 1330; Micromeritics Instrument Corp, Norcoss, GA, USA). The mass (m_ρ) of pellets (~4 g) in the sample cup of the pycnometer was obtained with a digital balance accurate to 0.001 g (Model AR3130; Ohaus Corp., Pinebrook, NJ, USA).

Figure 1 Working line of pelleting quail litter (QL) using Siriwan Model machine.

Porosity

The porosity (ε) of each sample pellet was calculated from the measured values of bulk density and particle density (Alemi *et al.* 2010) using the following equation:

$$\varepsilon = 1 - (\rho_b/\rho_\rho)$$

where ρ_b = bulb density of pellet (kg/m^3) and ρ_ρ = particle density of pellet (kg/m^3).

Durability

The durability (Du; %) of each sample pellet was determined according to ASAE Standard, S269.4 (ASAE 2002). A 100 g sample of pellet was tumbled at 50 rpm for 10 min, in a dust-tight enclosure. A no. 5 US sieve with an aperture size of 4 mm was used to retain crumbled pellets after tumbling. Durability is expressed by the percent ratio of mass of pellets retained on the sieve after tumbling (m_{pa}) to mass of pellets before tumbling (m_{pb}) using the following equation:

$$\mathrm{Du} = 100\,(m_{pa}/m_{pb})$$

where m_{pa} = mass of pellets retained on the sieve after tumbling (g) and m_{pb} = mass of pellets before tumbling (g).

Durability is said to be high when the measured value is above 80%, medium when between 70% and 80%, and low when below 70% (Tabil & Sokhansanj 1996; Adapa *et al.* 2003; Fasina 2008).

Rupture force

The rupture force (Rf; N) of each sample pellet was processed according to the McMullen *et al.* (2005) methodology. A texture analyzer (Model TA-HD, Stable Micro Systems, Surrey, UK) was used to measure the force required to rupture 50 pellets from each sample. This was achieved by placing the pellets on a flat plate in its natural position (i.e. the radial dimension was in the same direction as that of the compressive force). A flat plate (50.8-mm diameter) plunger was then pressed onto the pellet at a speed of 10 mm/s. The maximum force (N) needed to rupture the pellet sample that was determined from the force-deformation curve recorded by the computer interfacing with the texture analyzer.

Decomposition

The decomposition (De; %) of each sample pellet was processed according to procedures of Suppadit (2009b). Fifty pellets from each sample were placed outdoors in an open field. After 4 weeks, the pellets were oven dried at 65–70°C for 24 h for dry matter (as basis) determination using a specified drying method (Model Sharp IEC, Tokyo, Japan). The decomposition was calculated using the following equation:

$$\mathrm{De} = 100\,(dm_b - dm_a)/dm_b$$

where dm_b = Dry matter as basis of pellets before decomposition (g) and dm_a = Dry matter as basis of pellets after decomposition (g).

Estimation analysis

Linear regression analysis was used to investigate the possible utility of moisture content as an estimator of physical characteristics. All statistical analyses were performed with the statistic package SPSS 15.0 (Leech *et al.* 2007).

RESULTS AND DISCUSSION

Physical parameters

Bulk density

The bulk density (ρ_b; kg/m^3) of QL pellets varied from about 663 to 800 kg/m^3 (Fig. 2). This was in contrast to a bulk density of 200 kg/m^3 for the fresh litter reported by McMullen *et al.* (2005). Pelleting, therefore, could decrease the amount of space required to store QL by more than three times.

There was a decreased linearly in bulk density as the moisture content of the QL increased. The decrease in the values of bulk density was due to the expansion of the pellet size, an increase in the volume of the pellets with an increase in moisture content (McMullen *et al.* 2005; Fasina 2008). Therefore, the amount of storage space that would be required per unit mass of material would increase with increase in moisture content. Similar results were obtained from moisture effects on bulk density of alfalfa pellets (Fasina & Sokhansanj 1993), wet compost pellets (Masayuki 2001), poultry litter pellets (McMullen *et al.* 2005) and peanut hull pellets (Fasina 2008). The following equation was used to relate the bulk density of the pellets to moisture content (MC):

$$\rho_b = [-4.559 \times \text{MC}\,(\%\ \text{wet basis})] + 848.0;\ R^2 = 0.985.$$

Particle density

The particle density (ρ_p; kg/m^3) of QL pellets varied from about 1700 to 1953 kg/m^3 (Fig. 3). It increased linearly with an increase in moisture content of fresh QL, while contrasting to the bulk density of QL pellets. This indicated that the change in volume of individual pellets was smaller than the change in corresponding mass of the pellet per unit of an increase in moisture content. Similar results were obtained from moisture effects on particle density of poultry litter pellets (McMullen *et al.* 2005) and manure pellets (Alemi *et al.* 2010). The following equation was used to relate the particle density of the pellets to moisture content (MC):

$$\rho_p = [8.467 \times \text{MC}\,(\%\ \text{wet basis})] + 1617;\ R^2 = 0.993.$$

Porosity

The porosity (ε) of QL pellets varied from about 0.529 to 0.660 (Fig. 4). The porosity was estimated by applying the measured values of the bulk and particle densities. The result showed that the porosity increased linearly with the increase in moisture content, similar to the results with the particle density. This agreed with the studies of McMullen *et al.* (2005) and Alemi *et al.* (2010). The following equation was used to relate the porosity of the pellets to moisture content (MC):

$$\varepsilon = [0.004 \times \text{MC}\,(\%\ \text{wet basis})] + 0.487;\ R^2 = 0.993.$$

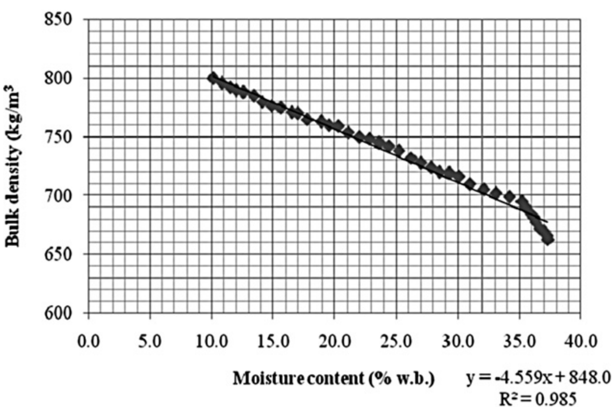

Figure 2 Effect of moisture content on bulk density.

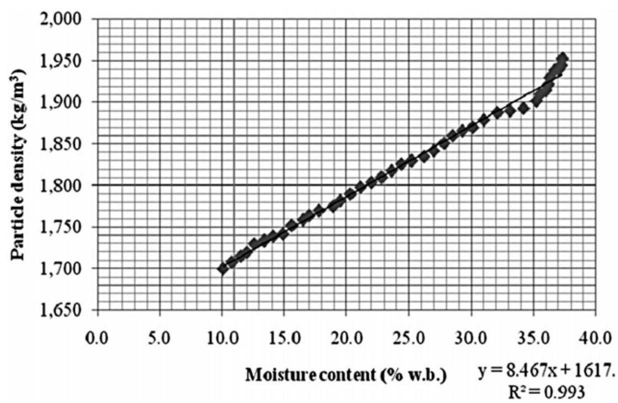

Figure 3 Effect of moisture content on particle density.

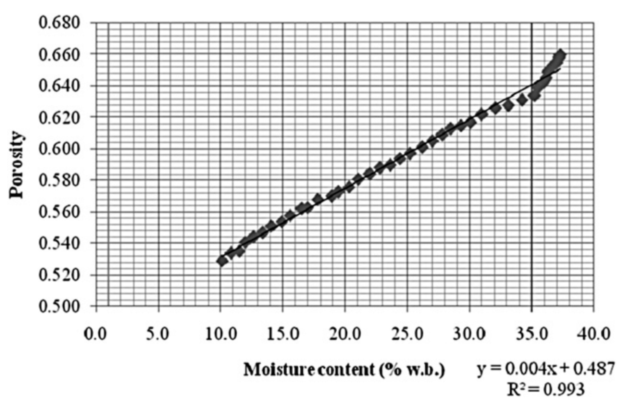

Figure 4 Effect of moisture content on porosity.

Durability

The durability (Du; %) of QL pellets varied from about 73.3% to 95.5% (Fig. 5). There was a decrease linearly in durability as the moisture content of the QL increased. At moisture contents greater than critical level, the binding forces pulling the particle together are less than the forces pulling the particle due to volume expansion of the pellets (McMullen *et al.* 2005). This is similar to the trend that was reported for alfalfa pellets (Tabil & Sokhansanj 1996), poultry litter pellets (McMullen *et al.* 2005) and peanut hull pellets (Fasina 2008). The following equation was used to relate the durability of the pellets to moisture content (MC):

$$Du = [-0.703 \times MC\,(\%\ \text{wet basis})] + 103.4;\ R^2 = 0.974.$$

Rupture force

The rupture force (Rf; N) of QL pellets varied from about 30.0 to 260 N (Fig. 6). It was more sensitive to moisture change than pellet durability. There was a decrease linearly in rupture force as the moisture content of the QL increased. Therefore, the pellets offered less resistance to quasi-static compressive loading as moisture content increased. Moisture decreased the strength of bonds holding the pellet particles together, thus making the pellets more friable (McMullen *et al.* 2005). This is similar to the trend that was reported for poultry litter pellets (McMullen *et al.* 2005) and peanut hull pellets (Fasina 2008). The following equation was used to relate the rupture force of the pellets to moisture content (MC):

$$Rf = [-7.447 \times MC\,(\%\ \text{wet basis})] + 303.1;\ R^2 = 0.933.$$

Decomposition

The decomposition (De; %) of QL pellet varied from about 50.3% to 90.0% (DM basis) (Fig. 7). Decomposition of QL pellets increased with an increase of moisture content in fresh QL. This is in contrast to the durability. In general, when moisture content of the biomass increased, pellet solidity and compactness decreased (Suppadit & Panomsri 2010). The slow nutrient decomposition could reduce leaching and losses of nutrient and increase fertilizer usage efficiency in upland soils (Alemi *et al.* 2010). The following equation was used to relate the decomposition of the pellets to moisture content (MC):

$$De = [1.317 \times MC\,(\%\ \text{wet basis})] + 40.57;\ R^2 = 0.987.$$

Statistical analysis of QL physical parameters

Pearson correlation analysis

Pearson correlation analysis of moisture content, bulk density, particle density, porosity, durability, rupture force and decomposition of QL was carried out in order to measure the relationship between seven individual physical parameters (Table 1). All correlation coefficients (r) were of sufficient magnitude to ensure that the correlations between two physical parameters were statistically significant at

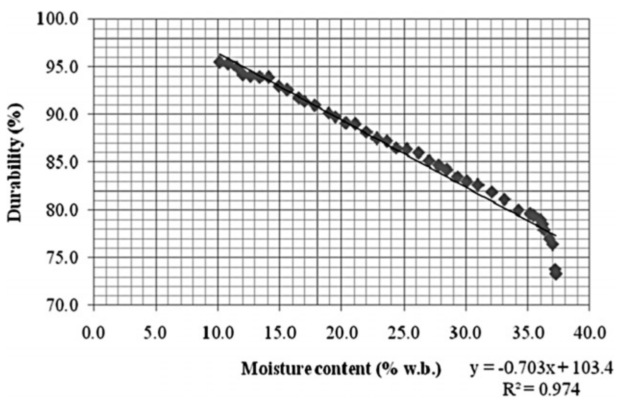

Figure 5 Effect of moisture content on durability.

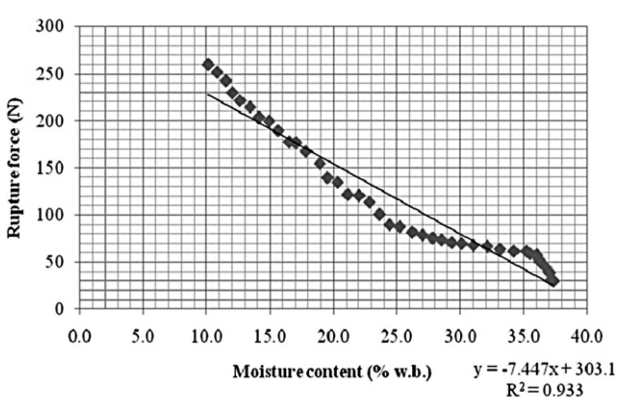

Figure 6 Effect of moisture content on rupture force.

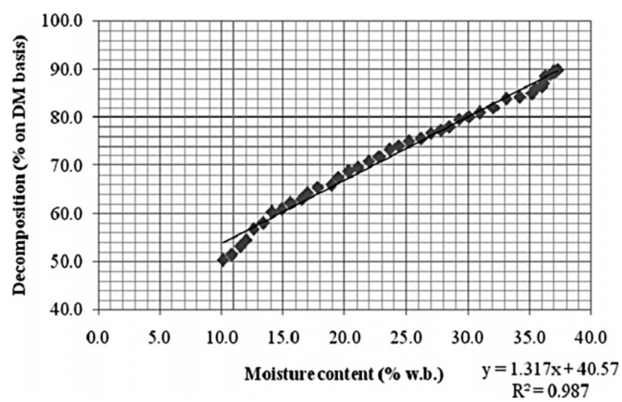

Figure 7 Effect of moisture content on decomposition.

Table 1 Pearson correlations of moisture content, bulk density, particle density, porosity, durability, rupture force and decomposition of quail litter

	Moisture content	Bulk density	Particle density	Porosity	Durability	Rupture force	Decomposition
Moisture content	1.00	−0.992	0.997	0.997	−0.987	−0.966	0.994
Bulk density	−0.992	1.00	−0.997	−0.997	0.996	0.945	−0.985
Particle density	0.997	−0.997	1.00	1.00	−0.994	−0.964	0.993
Porosity	0.997	−0.997	1.00	1.00	−0.993	−0.965	0.994
Durability	−0.987	0.996	−0.994	−0.993	1.00	0.943	−0.980
Rupture force	−0.966	0.945	−0.964	−0.965	0.943	1.00	−0.983
Decomposition	0.994	−0.985	0.993	0.994	−0.980	−0.983	1.00

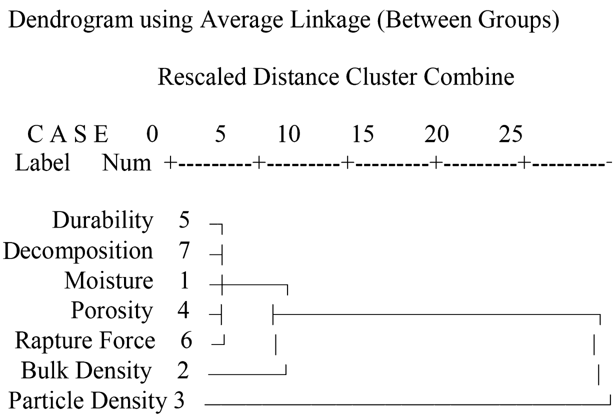

Figure 8 Hierarchical cluster analysis of moisture content, bulk density, particle density, porosity, durability, rupture force and decomposition of quail litter (QL.).

$P < 0.05$. As illustrated in Table 1, strong positive correlations were observed in the combinations of particle density–moisture content ($r = 0.997$), porosity-moisture content ($r = 0.997$), decomposition–moisture content ($r = 0.994$), durability–bulk density ($r = 0.996$), rupture force–bulk density ($r = 0.945$), particle density–decomposition ($r = 0.993$), porosity–decomposition ($r = 0.994$) and durability–rupture force ($r = 0.943$). Obviously, water content plays an important role on particle density, porosity and decomposition. To achieve a high quality of pelleting, it is therefore necessary to enhance more efforts on reducing the water content in QL. It is also worth noting that positive correlations between durability–rupture forces and particle density–decomposition coupled with porosity–decomposition, emphasize reliabilities of the analytical methods.

Hierarchical cluster analysis (HCA)

The cluster analysis revealed the presence of three different groups as displayed in Figure 8. In the dendrogram the first cluster consists of durability, decomposition, moisture, porosity and rupture force. Despite using different statistical algorithms, the water content still shows strong associations with analytical parameters related to the strengths and physical tolerances of QL pellets as confirmed by correlation analysis. The second cluster is composed of bulk density, which is positioned between 'rupture force' and 'particle density'. This can be attributed to the fact that both particle and bulk densities can positively influence on rupture force and thus it seems reasonable to consider density as an important physical parameter crucially affecting pellet quality. The last cluster is comprised of 'particle density'. The highest dissimilarity positions appeared in the dendrogram between 'particle density' and 'durability' reflecting the limitations of density in assessing the durability of QL pellets. Since durability is calculated by using the percent ratio of mass of pellets retained on the sieve after tumbling (m_{pa}) to mass of pellets before tumbling (m_{pb}), while particle density is computed by using the ratio of pellet mass to pellet volume, it appears logical to interpret this dissimilarity as a result of differences in analytical methods.

Principal component analysis (PCA)

Table 2 displays the principal component patterns for Varimax rotated components of the physical parameter data set of moisture content, bulk density, particle density, porosity, durability, rupture force and decomposition of QL. In order to enable further assessment of closeness among physical parameters, a PCA model with five significant PCs, each representing 98.6%, 1.14%, 0.143%, 0.0510% and 0.0290% of the variance, thus accounting for 99.9% of the total variation in the data, was calculated. The first component (PC1) shows moderate positive loading on moisture content ($r = 0.752$), particle density ($r = 0.771$), porosity ($r = 0.769$) and decomposition ($r = 0.703$). These results confirm that water content still plays an important role on particulate specific weight, void spaces in a material and the process by which organic material is broken down. The negative correlations with bulk density ($r = -0.810$), durability ($r = -0.815$) and rupture force ($r = -0.578$) reflected the fact that higher moisture content caused greater porosity, coupled with decomposition rate and thus lower bulk density, durability and rupture force of pellets.

Table 2 Principal components analysis (PCA) of moisture content, bulk density, particle density, porosity, durability, rupture force and decomposition of quail litter

	PC1	PC2	PC3	PC4	PC5
Moisture content	0.752	0.649	0.114	0.0160	0.00500
Bulk density	−0.810	−0.583	−0.0340	−0.0270	−0.0290
Particle density	0.771	0.635	0.0430	0.0200	0.0230
Porosity	0.769	0.637	0.0410	0.0300	0.0240
Durability	−0.815	−0.578	0.00700	0.00500	0.0380
Rupture force	−0.578	−0.816	−0.0160	0.00200	−0.00100
Decomposition	0.703	0.706	0.0520	0.0730	0.00400
Varimax rotation (%)	98.6	1.14	0.143	0.0510	0.0290

Extraction method: PCA. Rotation method: Varimax with Kaiser normalization.

Conclusion

Data on the physical characteristics (bulb density, particle density, porosity, durability, rupture force and decomposition) of QL pellets were obtained. All the physical characteristics of QL pellets depended on their moisture contents. Bulk density, durability and rupture force of the pellets decreased, while particle density, porosity and decomposition of the pellets increased linearly with increase of moisture content. Furthermore, Pearson's correlation analysis, HCA and PCA emphasized 'moisture content' as the most crucial physical parameters affecting the quality of QL pellet samples. Pelleting could be used as a method to increase the bulk density of QL to economically transport the litter from the quail farm, reducing leaching losses and enhancing nutrient uptake by plants.

ACKNOWLEDGMENTS

The authors wish to thank the Siriwan Company Limited for experimental materials and also The Thailand Institute of Scientific and Technological Research and Chiang Mai Field Crops Research Center, Thailand for supporting some parts of the laboratory.

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