BALE BAGGING EFFECT ON BALE WEIGHT CHANGE DURING STORAGE: MEASURED AND MODELED

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Abstract

Universal Density cotton bales were formed with relatively dry lint, covered with different types of cotton bale bagging materials, and the bales stored in a humid environment for more than 3 months. The bale coverings included coated woven polypropylene with and without holes, linear low density polyethylene film with different hole patterns, and no bale bagging. The bales were weighed periodically during storage. Some bales were then exposed to drier conditions and the weight change over time again recorded. The bale weight changes were modeled with a single term decaying exponential. Different bales in the same bagging type changed weight consistent with the models. The rate of bale weight change from the models was used to calculate a half time to equilibrium, in days, for each bagging type. The half time for bales with no bagging was 13 days, for bales in coated woven polypropylene bagging with holes punched in it was 34 days, and for bales with an experimental bagging made of polyethylene film with small holes was 172 days. This half time number will allow simplified communication of the effect bale bagging has on the rate of change of cotton bale weight during storage.

Introduction

In US commerce cotton bales weighing approximately 500 lb are covered with bagging to protect them during transportation and storage. Individual bagging designs are reviewed and approved for use by the Joint Cotton Industry Bale Packaging Committee (JCIBPC) coordinated by the National Cotton Council. For a particular bagging design to be accepted for use by the US industry it must be approved by representatives from cotton farmers, ginners, cotton warehousing, cotton merchants, and mills. These segments sometimes have different interests, the farmers and ginners have to purchase the bags and would prefer minimum price. The warehousemen have to handle the bales, often multiple times, and would prefer durable bags so that they do not have to repair them. The mill operators want bags which have protected the cotton from contamination which are also easy to handle and recycle.

Cotton is sold by weight without regard to moisture content (mc). Years ago burlap bagging, which was relatively permeable to moisture, was used and the bales were not fully covered. With this covering design the US cotton bales typically came to equilibrium with ambient conditions relatively rapidly while being stored in warehouses located in humid areas during winter months before being spun in mills located in Virginia or North Carolina. In addition to the change in bale weight affecting the total price, the higher mc cotton fiber was stronger and better able to resist damage during the cleaning and spinning processes at the mill. More recently the JCIBPC promoted fully covering bales for cleaner cotton at the mills and woven polypropylene (WPP) was adopted in many cases for its price, light weight, and strength. Anthony (1982) showed that these bags were as permeable to moisture as were the burlap bags. However, when the WPP bags were cut, usually in bale sampling or handling, they released fibers which could become entangled with the cotton fiber. So, the JCIBPC called for coating the bags to contain any fibers. The coating significantly reduced moisture permeability so the coatings were applied in strips or holes were made in the coatings which improved the permeability (Anthony and Herber, 1991). But in order to better control possible loose fibers the current standard calls for complete coating of the WPP bags with Linear Low Density Polyethylene (LLDPE).

More recently bags made from LLDPE film have increasingly been used, mostly because of price. These bags are much less permeable to moisture (Anthony, 1982; Anthony and Herber, 1991) and lose strength when holes are made in them. LLDPE bags are popular without holes, however, the JCIBPC is insisting on examining LLDPE bags with improved permeability achieved through various hole sizes and patterns.

Anthony and Herber (1991) published information on the affect bale bagging had on UD bale weight change over time. They included 3 types of WPP bags coated in different width strips, and one LLDPE bag with 3/8 in diameter holes on 18 in centers. Two of the WPP bags had coatings covering about half of the bag and the bales in those bags had the highest weight change. The third type of WPP bag was coated on about 86% of the surface and the bales with those bags had slower weight gain. The bales stored in LLDPE bags with holes covering about 0.12% of the surface had by far the slowest weight gain.

Two fully coated and 2 strip coated WPP bags were studied as described by Anthony (2005c) and different bales but with the same bagging by Anthony (2005a). The two strip coated WPP bags were from different manufacturers and had different details of bag construction but each had about 50% coating. One bag was fully coated and also had the bag seam coated while the other fully coated bag had an approximately 3 in wide strip including the seam uncoated. The bales in the 2 different strip coated bags had approximately the same rate of weight gain, the bales in the fully coated bag with the seam uncoated had a lower weight change rate and the lowest weight change rate was for the bales with fully coated bags including coating the seam. Anthony (2005a) also included some data with decreasing bale weights when the bales were stored in a drier environment which appeared to have the same weight change relationship.

Anthony (2005b) used three bagging types; fully coated WPP, fully coated WPP with uniformly spaced pinholes, and strip coated WPP; with three UD bales each and collected weight data as they gained weight in a high humidity environment then lost weight in a low humidity environment. The bales in strip coated bags gained weight the fastest, those in bags with pinholes more slowly, and those in fully coated bags with no holes the slowest.

The moisture ratio has often been used when products are studied with changing moisture content but assuming the weight of the dry matter in bales does not change when fiber mc changes the moisture ratio is equal to the bale weight ratio, WR, defined as:

$$WR = (W(t) - EW)/(W(0) - EW) \tag{1}$$

where
W(t) = the bale weight at time=t
EW = the equilibrium bale weight, and
W(0) = the bale weight at time=0

Many agricultural researchers have used the model:

$$\text{Moisture ratio} = \exp(-b*t) \tag{2}$$

where b = a drying constant with units of time^{-1}. Equations 1 and 2 can be combined and rearranged as:

$$W(t) = (W(0) - EW) * \exp(-b*t) + EW. \tag{3}$$

If data were collected for bale weight over time nonlinear regression can fit the data with the model:

$$W(t) = a * \exp(-b*t) + c \tag{4}$$

where a, b, c = parameters chosen by regression

The parameter c would be the equilibrium bale weight, b is the weight change coefficient related to time, and the parameter a represents the total bale weight change. Fitting equation 4 to data is fairly simple and the model allows bales of different original weights, different total weight change, and bale equilibrium weight to be normalized so that they can be compared more easily. The model would not be expected to fit the data well at small time, the time it takes for the first 5 to 10% of the total weight change. If the model fits the data well it would not be necessary to collect data until the bale reaches equilibrium but the equilibrium bale weight could be projected from the data. The decaying exponential model is common in engineering work and has many useful properties including that the period of time for the weight to change from the original to half the original would be the same no matter when on the curve the measurement started. This time period for half of the bale weight change to occur could be used as an indicator of speed of bale weight change.

The purpose of this study was to examine the weight change of cotton bales with different bagging related to moisture changes caused by ambient conditions. These data were then used to classify the bale bagging for the rate of weight change of the bales.

Materials and Methods

This study was done in three parts. In Part I with data collected by Anthony (2005b) the weight change related to bales of low moisture lint stored in a humid environment with different woven polypropylene bagging, in Part II the data from Anthony's same study with bales exposed to a lower humidity environment resulting in decreasing weight. Part III examined the weight change of dry cotton in bales as the weight increased with two bales with no bagging, two bales with woven polypropylene bagging, and eight bales with three different LLDPE bags.

The procedures used in data collection for Parts I and II are documented by Anthony (2005b). Three types of bagging were used with three bales per bagging type, Table 1. The bales were stored at high humidity for 186 days, but conditions were less well controlled after day 115. Three of the bales were opened to obtain samples for mc determination and the remaining bales were then stored at a lower humidity for 367 days. The bales were each weighed periodically during the storage to create a data set of bale weights over time as the bales gained or lost weight.

Twelve bales of cotton were ginned for Part III on July 19, 2007 and the bales were placed in the selected bagging then moved into storage at controlled relative humidity (RH) and temperature the same day. Table 1 shows the types of bagging used and the bale numbers to which each was applied. The bales were weighed individually during the storage period to create the data set of bale weights over time. Figure 1 shows one of the bales on the scale used to weigh the bales.

Table 1. Bale bagging included in the study.

Study Part	Bagging ID used	Description of bagging	Bale numbers
I and II	WPPpin	Woven polypropylene fully coated with uniformly spaced pinholes, JCIBPC 2003 experimental test program, Propex type 9722	1325, 1327, 1334
I and II	WPPcoated	Woven polypropylene fully coated, approved for use in 2003, Propex	1326, 1331, 1333
I and II	WPPstrip	Woven polypropylene diagonally sown of alternatively 1 cm coated and 2 cm uncoated strips, Propex	1330, 1332, 1335
III	None	Bare cotton bales with no bagging	2235, 2236
III	LLDPEpinl	LLDPE with 0.05” dia. pinholes punched on a 1" grid covering the bag, FlexSol Packaging	2225, 2226
III	LLDPEpins	LLDPE with 0.025” pinholes punched on a 1" grid covering the bag, Poly Plastic Products	2227, 2228
III	LLDPEpinstrip	LLDPE with six 4 1/2" wide strips of pinholes, with 11.5 holes/square inch, Lone Star Plastics	2229, 2230, 2231
III	WPPvh	Woven polypropylene fully coated with twenty 1 1/2" dia. semicircular vent holes around the bottom, Intertape Polymer Group	2232, 2233, 2234

Figure 1. Photo showing one bale included in the test being weighed.

The bale weight data were modeled similarly for the three parts using equation 4. In Part I all bale weight data from day 6 through the 115 were included. The weight data were observed to not always be smoothly changing for the first few days and after day 115 for data set I the RH became poorly controlled. The SAS (2003) procedure NLIN, a program for nonlinear regression, was used to fit the model to the data with 27 parameters, 3 for each bale and 9 bales. Then the model was simplified by considering only one b parameter for each bagging type resulting in 21 parameters. The curves from the models were plotted to compare them with the observed data and to verify that the model fit the data. The time in days for a bale to change half the potential weight change was calculated based on the parameter b for different bagging types and tabulated. Several models representing the range of the parameter b were plotted together so that they could be compared visually.

Results and Discussion

In Part I the average temperature and RH for the storage of the bales was 74 °F and 72%. The initial bale weights averaged 498 lbs. Parameters were chosen by fitting the model to the weight data based on equation 4 with the SAS procedure NLIN with three parameters for each bale for the 9 bales in Part I. Then the number of parameters was reduced by including one b parameter for all bales with the same bagging. Both models fit the data well with an F=2854 for the first model and F=3669 for the second. The second model fit better because the F value was larger and used fewer parameters. The measured bale weight with the parameters a and c were used to calculate a weight ratio as defined by equation 1 for each bale weight. Figure 2 shows the bale weight ratio data plotted with different symbols for the three bagging types and the three models for the three bagging types. There was a short term but substantial drop in RH observed on day 39 which is reflected in all bale weight changes on this plot, but overall the model fit the data well over the 115 day period. Based on the large F value and Figure 2 the model fit the data well.

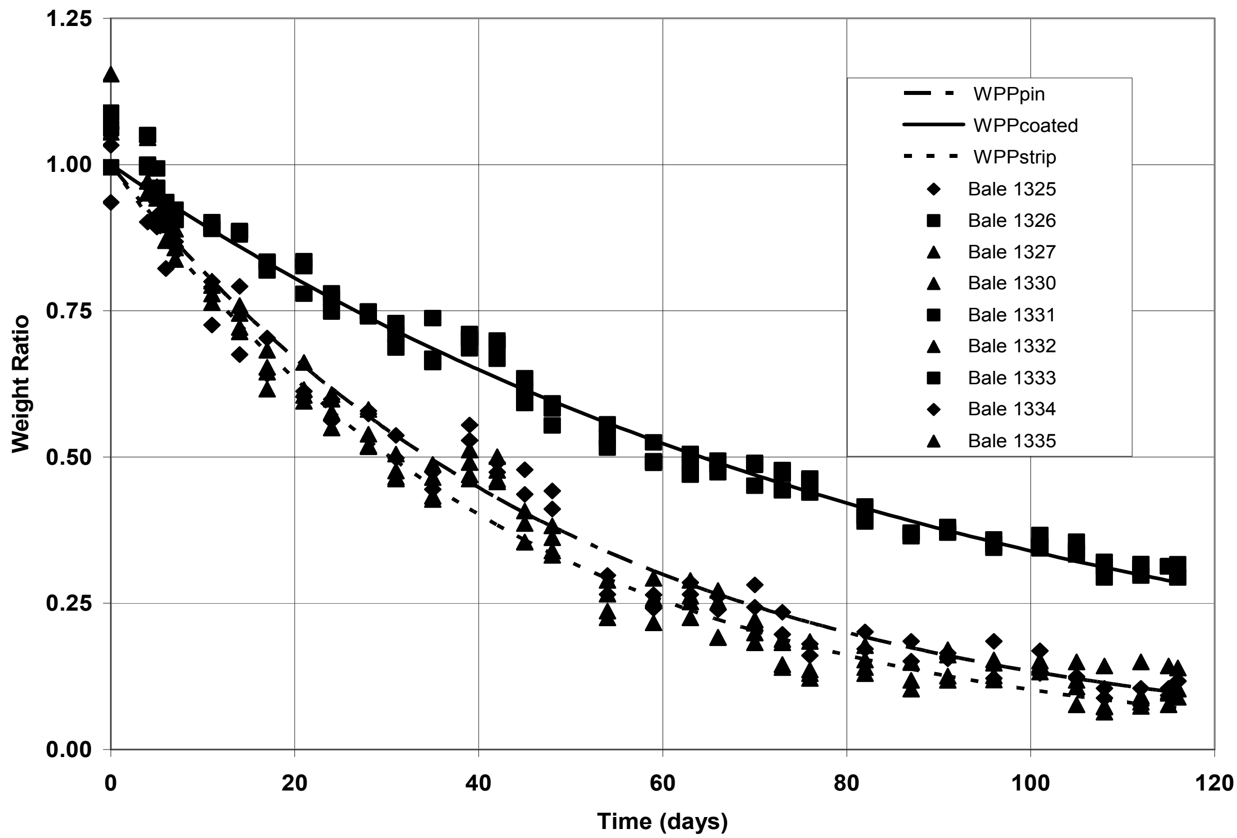

Figure 2. Plot of the weight ratio for 9 bales over time, points, and the three models based on nonlinear regression for the three bale bagging materials, lines, with increasing bale weights, Part I.

In Part II the average temperature and RH for the storage of the bales was 70 °F and 45%. The model was fit to the data in the same way as in Part I. Using 3 parameters per bale resulted in F=3754 but when the different values for b were reduced to one per bale bagging material instead of one per bale the F=4339. This showed that the model with one slope per bagging material was the preferred model. Figure 3 shows the individual bale weight ratio data along with the models for each bagging type.

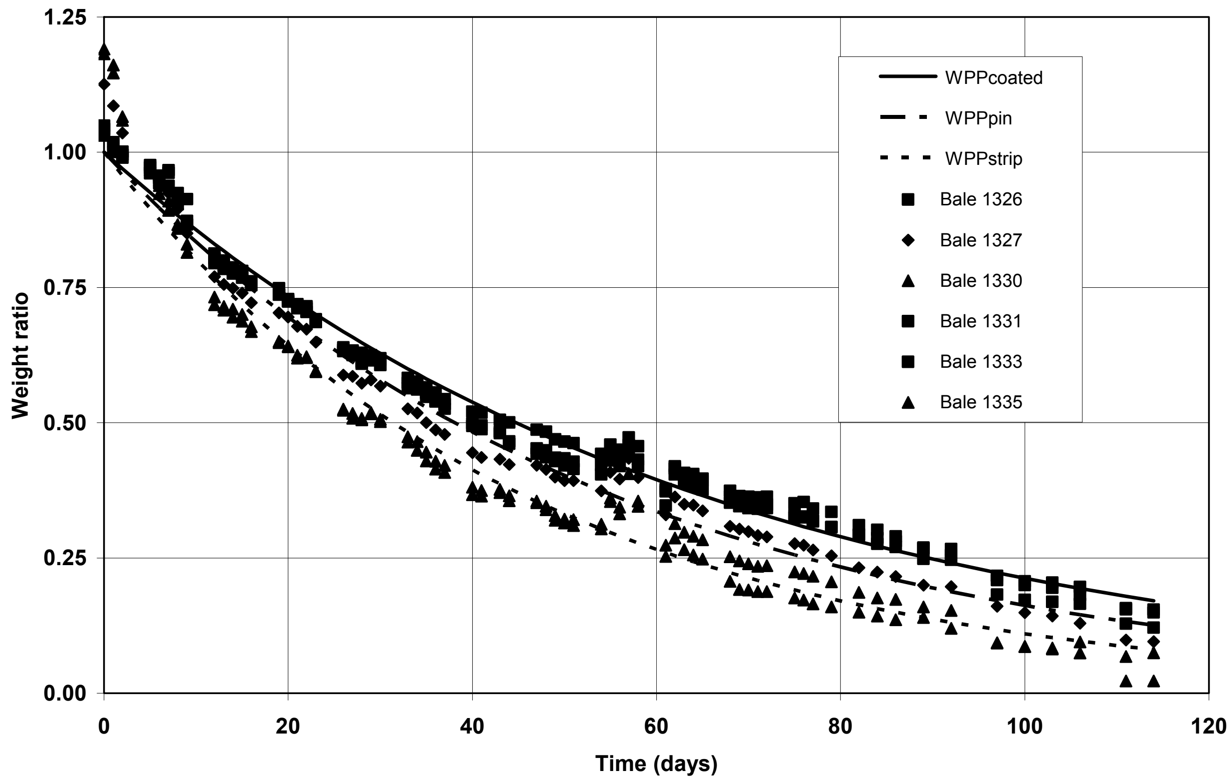

Figure 3. Weight ratio change for bales with three different bagging materials with decreasing weights, Part II, observed moisture ration data, points, and mathematical models from nonlinear regression, lines.

The estimated bale weight change parameter values for the three types of bagging with weights increasing and decreasing are shown in Table 2 along with the standard errors of those estimates. For the fully coated bagging the rate of weight change was higher for decreasing weight than for increasing weight. This could have been because the bagging was damaged during handling which allowed more exposure after the damage, or because it is an inherent property of the bagging or cotton lint. The rates of change for the bagging with pin holes, WPPpin, was numerically different but could not be considered to be significantly different based on the standard error of the estimate whether the bales were gaining or losing weight. The rate of change with the strip coated bagging, WPPstrip, was nearly identical for the bales gaining and losing weight. These observations would support the probability that the WPPcoated bagging was changed, damaged, for the fully coated bags leading to higher transfer rates in the second portion of the test. Each bale was moved to and from the scale each time it was weighed and Part I lasted for 186 days before the same bales with the same bagging were used for Part II. Also the bales with WPPcoated bagging would be less uniform when the direction of moisture movement was changed and the higher mc lint would be located nearer the surface of the bale so that it would be easier to remove.

Table 2. Weight change coefficient from nonlinear modeling for bale weight gain and loss, Parts I and II.

Material	Weight increasing, Part I		Weight decreasing, Part II	
	Parameter estimate	Standard error of the estimate	Parameter estimate	Standard error of the estimate
WPPcoated	0.0108	0.00124	0.0155	0.00066
WPPpin	0.0201	0.00113	0.0182	0.00092
WPPstrip	0.0228	0.00144	0.0221	0.00073

In Part III the average bale storage temperature was 82 °F and 76% RH. The mean mc of the 5 samples for each of the 12 bales when they were ginned was 3.8% wb. The average bale weight was 484 lb and tables 3 and 4 list these bale weights over time. The weights of the 12 bales were modeled with 36 parameters resulting in F=21688. When one parameter was used for each bale bagging material for the same data set there were 29 parameters resulting with F=23238 for a slightly better fit. Figure 4 shows the fit of the model to the three bales bagged in WPPvh and Figure

5 shows the 5 models obtained by nonlinear regression and the data from one bale bagged in each type of bagging. As can be seen from Figure 5 the bare bales changed weight much more rapidly than the bales in any of the bagging materials and the use of LLDPEpins bagging resulted in lower weight change rate than the other materials.

Table 3. Bale weights over time for two uncovered and two bales with two types of bagging.

	Bale number					
Days of storage	2225	2226	2227	2228	2235	2236
0	483.4	521.4	500.2	503.0	480.4	488.2
1	483.6	521.6	500.4	503.6	482.8	490.6
4	484.0	522.4	500.6	504.0	487.6	495.4
5	484.2	522.4	501.0	503.8	488.6	496.2
6	484.4	522.6	500.6	504.2	489.2	497.4
7	484.2	522.4	500.6	504.4	489.8	497.6
8	484.4	522.6	500.6	504.2	491.0	498.8
11	485.0	523.4	501.0	504.4	493.4	500.8
12	484.8	523.4	501.0	504.2	494.2	501.6
13	485.2	523.8	501.2	504.2	495.0	502.2
14	485.6	524.0	501.6	504.8	495.6	503.0
15	485.8	524.0	501.6	505.0	496.2	503.0
18	486.0	524.6	501.6	505.2	497.6	504.6
20	486.0	524.6	501.4	505.0	498.0	504.8
21	486.0	524.6	501.4	505.0	498.2	505.2
22	486.2	525.0	501.8	505.0	498.4	505.6
25	486.0	525.2	501.6	505.2	498.2	505.4
26	486.4	525.4	501.6	505.0	498.6	505.8
28	486.4	525.4	501.8	505.2	498.4	506.2
32	487.0	526.2	502.2	505.8	499.2	507.0
34	487.0	526.4	502.4	505.8	499.2	507.2
36	487.2	526.6	502.6	505.8	499.2	507.6
40	487.6	527.0	502.6	506.2	499.0	507.2
42	487.8	527.2	502.8	506.6	499.4	507.8
47	487.6	527.4	503.0	506.4	499.8	507.6
50	487.8	527.4	502.8	506.4	499.8	507.6
56	488.0	528.0	503.0	506.6	501.2	509.4
61	488.4	528.4	503.4	507.0	501.6	510.0
67	489.2	529.4	503.8	507.8	501.2	510.2
74	489.4	530.0	504.0	507.6	502.6	511.4
83	490.0	530.6	504.6	508.4	502.8	512.2
90	490.6	531.2	504.6	508.6	503.0	512.6
97	490.6	531.8	505.0	508.6	503.4	512.8
104	490.6	532.0	505.0	509.0	503.4	513.0
111	491.0	532.4	505.4	509.2	503.4	512.6

Table 4. Bale weights over time for three bales each for two different bagging materials.

	Bale number					
Days of storage	2229	2230	2231	2232	2233	2234
0	490.6	448.8	465.4	481.8	487.4	463.8
1	491.2	449.0	465.8	481.8	487.6	464.0
4	491.6	449.8	466.2	482.4	488.4	464.4
5	491.8	450.0	466.4	482.6	488.8	464.8
6	492.0	450.0	466.4	482.6	489.2	464.8
7	492.0	450.0	466.6	482.8	489.0	464.8
8	492.4	450.2	466.8	483.0	489.4	465.2
11	493.0	451.0	467.4	483.8	490.4	466.0
12	493.0	451.2	467.8	484.0	490.8	466.2
13	493.4	451.2	468.0	484.2	491.2	466.6
14	493.8	451.6	468.2	484.6	491.6	466.8
15	494.0	451.8	468.4	484.6	491.8	467.2
18	494.4	452.4	469.0	485.4	492.6	467.4
20	494.2	452.0	468.8	485.2	492.4	467.2
21	494.6	452.0	469.0	485.2	492.4	467.6
22	494.6	452.4	469.4	485.4	492.8	467.8
25	495.0	452.8	469.4	485.8	493.0	467.8
26	495.2	452.8	469.4	486.2	493.2	468.0
28	495.4	452.8	469.8	486.2	493.6	468.4
32	496.0	453.2	470.4	487.0	494.0	469.0
34	495.8	453.8	470.6	487.2	494.2	469.2
36	496.2	454.4	471.0	487.6	495.0	469.8
40	496.8	454.4	471.4	487.8	495.2	469.8
42	497.0	454.8	471.6	487.8	495.6	470.2
47	497.4	455.0	472.0	488.4	496.0	470.6
50	497.2	455.0	472.2	488.6	496.2	470.4
56	498.0	455.2	472.6	489.2	496.6	471.4
61	498.4	456.2	473.0	490.0	497.6	472.0
67	499.2	456.6	473.8	490.2	498.6	472.8
74	499.8	457.2	474.2	491.0	498.8	473.2
83	500.4	458.0	475.2	491.6	499.6	473.6
90	501.4	458.6	476.0	492.0	500.2	474.4
97	501.4	458.8	476.0	492.6	500.6	474.8
104	502.0	459.0	476.0	492.8	500.8	475.2
111	502.2	459.2	476.6	493.4	501.4	475.8

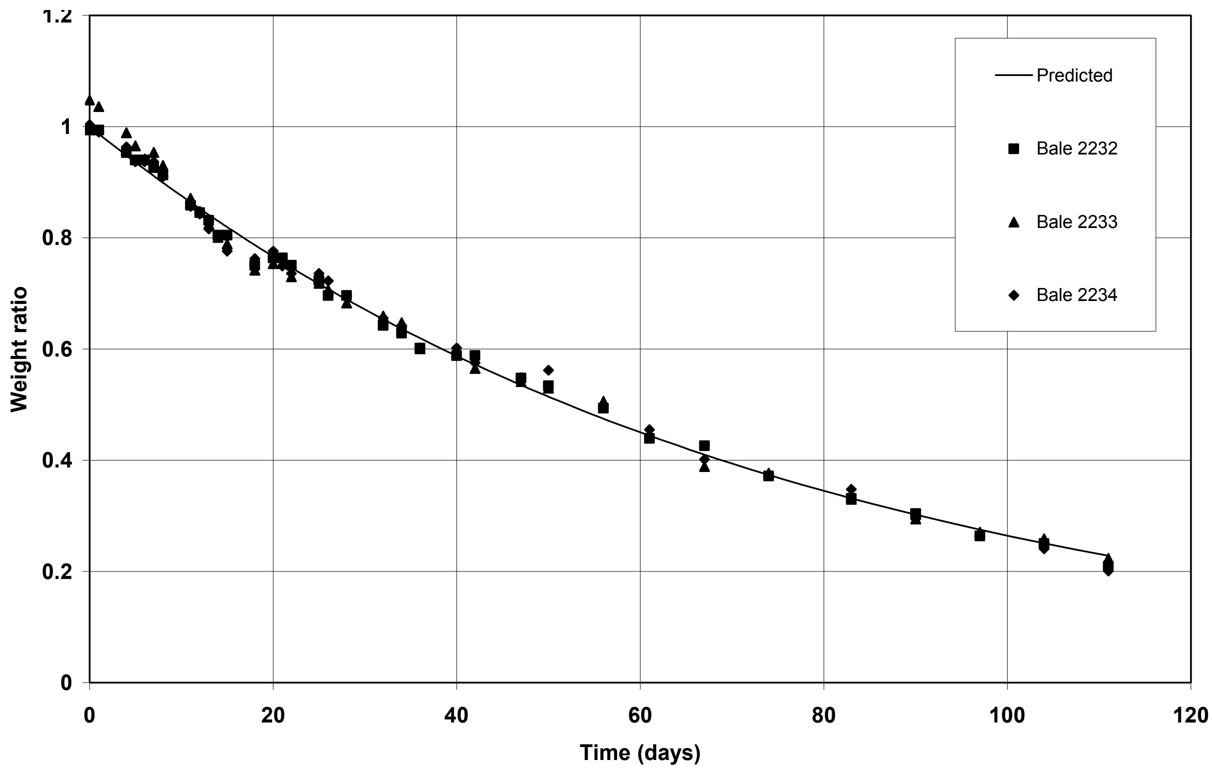

Figure 4. Bale weight ratio for the three bales with the woven polypropylene bagging with vent holes, points, and the model from nonlinear regression, line, Part III.

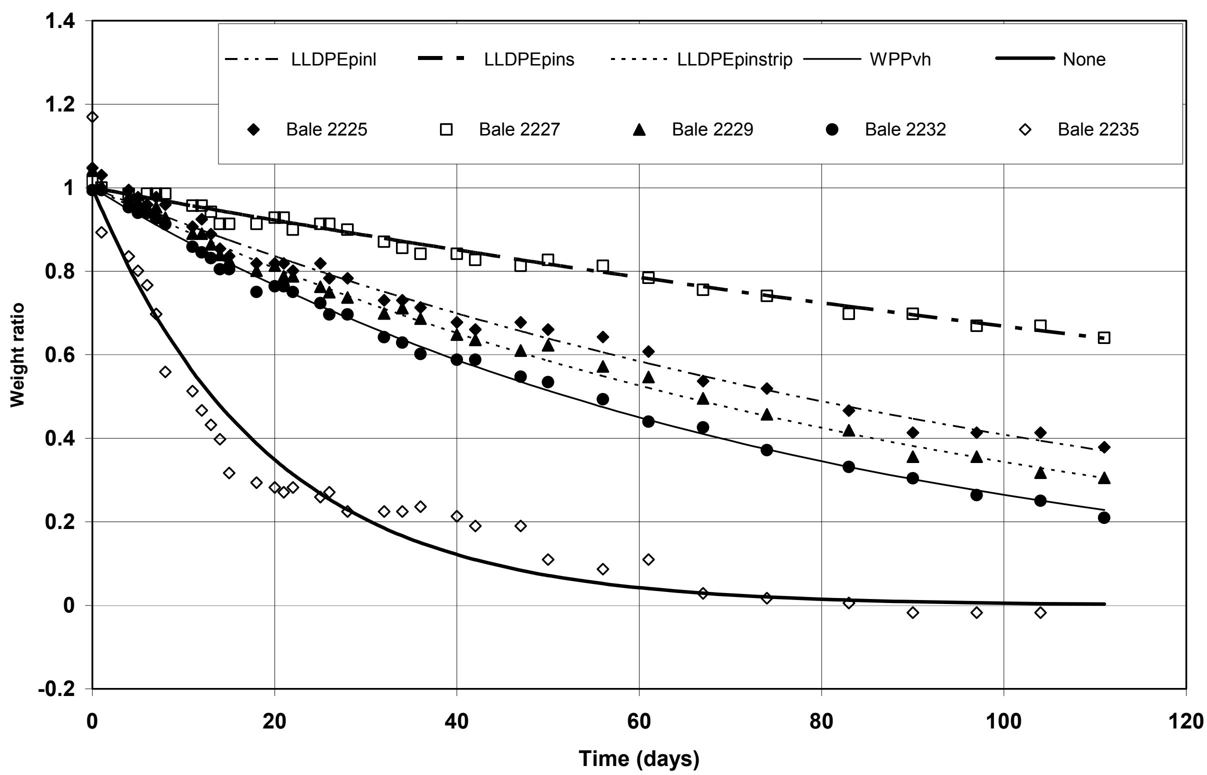

Figure 5. Individual bale weight ratio data, points, for one bale per bagging material and the model of the data over time, lines, of each bagging material, Part III.

The weight change coefficients determined in Parts I and III are listed in Table 4. In addition the time for half of the weight change to occur based on the models is listed. This demonstrates the substantial difference between no bagging, 13 days; the majority of the bagging, 35-70 days; and the LLDPEpins bagging, the least permeable at 172 days. It is interesting to note that the fully coated WPP bag had a much higher weight change rate than the LLDPE bag with small holes. The bale weight half time in days is a simple and valuable way of ranking cotton bale bagging. Use of this number would be a relatively simple way to understand and communicate a relatively complex issue, which is important to many involved in the marketing of cotton bales. Based on the half time to equilibrium it would take a bale in a WPPcoated bag about 192 days, or over 6 months, to change the same proportion as a bare bale would change in 39 days.

Table 5. Cotton bale bagging ID, weight change coefficient from equation 4, and half time to equilibrium for increasing bale weight.

Bagging ID	Coefficient b (days^{-1}) *	Half time to equilibrium (days)
LLDPEpins	-0.0040	172
LLDPEpinl	-0.0090	77
LLDPEpinstrip	-0.0107	65
WPPcoated	-0.0108	64
WPPvh	-0.0133	52
WPPpin	-0.0201	34
WPPstrip	-0.0228	30
None	-0.0527	13

* Differences of less than 0.004 are not statistically significant.

The models from Parts I and III are plotted in Figure 6. Two of the models were so close together that only one was included in this plot for clarity. The figure shows the same relationship graphically which is contained in Table 5. The number of days required for a change from the weight ratio of 1.0 to 0.5 is the half time to equilibrium. Other relationships can be seen in Figure 6, such as at the time at which a bale in WPPstrip bagging changed half the amount it would change, 30 days, a bale packed in WPPcoated bagging would have changed slightly more than half as much and a bare bale would have changed by about 80%. In the real world bales are not stored under constant temperature and RH. However, the same physical rules apply and a bale stored in WPPstrip bagging will make whatever changes the environment induces on it more than twice as fast as a bale stored in a WPPcoated bag.

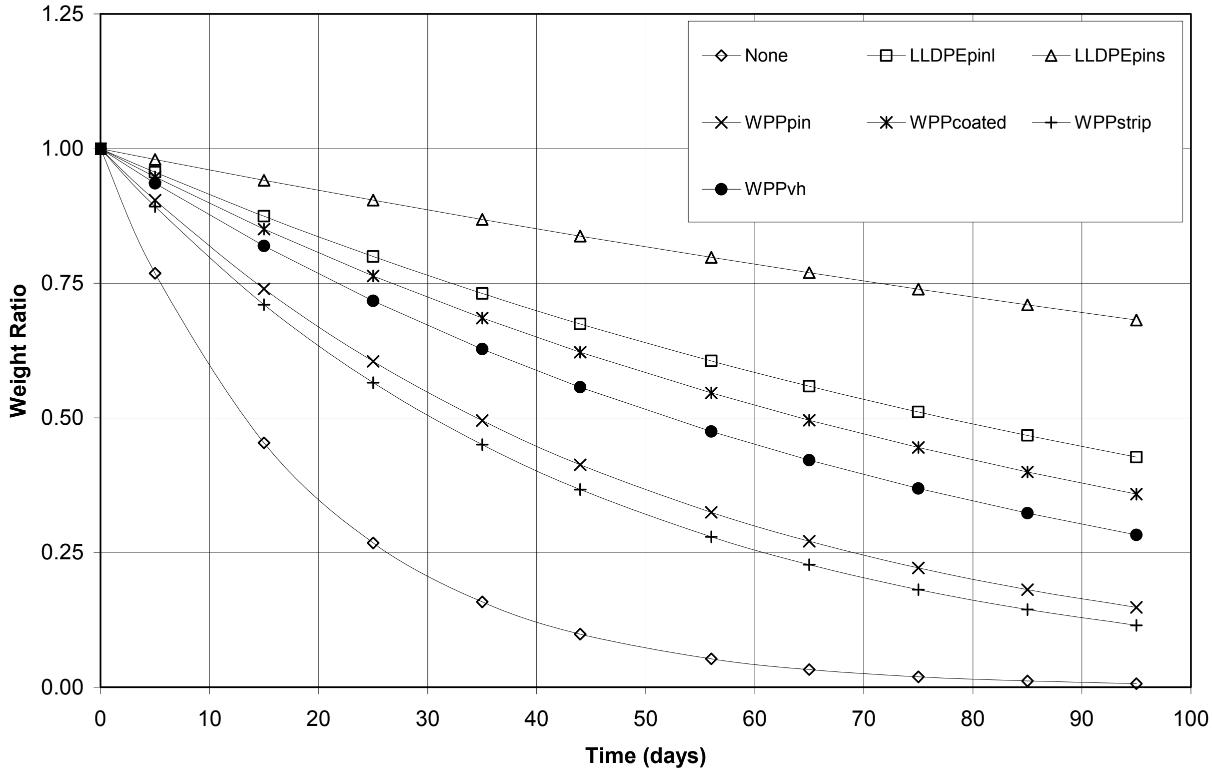

Figure 6. Seven of the models from Parts I and III representing the range of rate of bale weight change due to bale bagging with LLDPEpinstrip being almost identical to WPPcoated.

Summary

A total of 21 Universal Density cotton bales were placed in a total of 8 different bagging materials, including no bagging. The bales were stored in a chamber with relatively constant and high humidity with the bale weights being measured periodically. The weight data for the first few days was not included in the analysis and the bale weight data did not continue through the time of equilibrium. A single term exponential decay model was fit to the data which fit well with a different coefficient for initial bale weight, total bale weight change for each bale; and a different rate of bale weight change coefficient for each bagging material. The bale weight data for the two or three bales with the same bagging material agreed well.

The half time to bale weight change equilibrium was calculated for bales in each bagging type and varied from 13 days with no bagging to 172 days for a polyethylene bag with small holes. Some polyethylene bags with different hole patterns had a half time of 65 days. The bale with strip coated woven polypropylene bag had a half time of 30 days and the bag with fully coated woven polypropylene bag with pin holes had a half time of 34 days, times which were not significantly different, statistically.

The analysis of bale weight change data which produces a rate of bale weight change will allow the estimation of the half time to bale weight equilibrium without actually storing the bales until they approach equilibrium. The half time is a simple number which allows ranking bale bagging for those concerned with the rate of change of bale weight during storage. The number communicates in a simple way a rather complicated process which will allow better communication among those concerned with cotton bale weight changes during storage.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U. S. Department of Agriculture and does not imply approval of the product to the exclusion of others that may be available.

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