1794 Relationships between HVI, AFIS, and yarn tensile properties

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Cotton breeding programs must deliver fibers that perform better in textile manufacturing in order to compete effectively with the various man-made fibers and with international growths of cotton. While the improvement of fiber tenacity has been for many years the focus of these programs, elongation has not been included because calibration cottons are lacking. Yet, the work of rupture (of a bundle of fiber or yarn) is critically important and is determined by both tenacity and elongation. In this study, we demonstrated that a combination of fiber properties could provide good estimates of yarn elongation and yarn strength (ring spun yarn) over a large range of counts. Yarn elongation could be estimated from HVI elongation and HVI UHML (R-squared = 0.844) while yarn strength could be estimated from AFIS Mean Length by weight, AFIS Standard Fineness, and AFIS Maturity Ratio (R-squared = 0.938). Therefore, even though the HVI elongation measurement needs to be perfected, its use in breeding programs could lead to improved yarn quality and processing performance (from the gin to the shirt).

Key words: Tenacity, Elongation, Standard Fineness, Cotton

Introduction

Cotton breeding programs must strive to deliver fibers that perform better in textile manufacturing [1-3]. This is critical for effective competition with the various man-made fibers and with international growths of cotton. Yet, several fiber properties not measured in the cotton breeding programs have a large impact on processing performance. Among these are the elongation characteristics associated with fiber tenacity. Backe showed the importance of cotton fiber bundle elongation on yarn quality and weaving performances [4]. The author concluded that cotton fiber bundle elongation should be measured and seriously considered when developing cotton lay-downs. He reported that the higher the cotton fiber bundle elongation, all other fiber properties remaining constant, the better the yarn's quality and resistance to the stresses and strains of weaving. Inheritance of cotton fiber tenacity has been studied extensively. May et al. [1] reported that "heritability of fiber tenacity is generally high for selection units ranging from single plants to population bulks". He reported that among eighteen studies undertaken between 1954 and 1994, the narrow sense heritability for fiber tenacity ranged from 0.10 to 0.86. The same author reported that for fiber elongation the narrow sense heritability ranged from 0.36 to 0.90. May et al. also reported negative correlations between fiber elongation and fiber tenacity [5].

In general, most of the breeders simply ignore fiber elongation because the lack of calibration procedures for HVI elongation makes it impossible to rely on such data in an open market. In addition, the literature produced by cotton breeders shows that even when elongation measurements are available (Stelometer tests) there is a lack of understanding of its meaning. Indeed, because of the negative correlation between elongation and tenacity, they often conclude that there is no need to work on elongation because it could result in lower tenacity. We demonstrated in a previous paper [6] that this negative correlation indeed exists but it is a weak correlation that does not preclude the simultaneous improvement of tenacity and elongation.

In the same study Benzina et al [6] measured cotton fiber bundle elongation and tenacity using a modified tensile testing instrument to which Pressley clamps (1/8" gage length) were adapted. The work of rupture was calculated from the curves Load versus Elongation for each cotton, and then correlated to the product Tenacity*Elongation as determined by HVI. The coefficient of determination obtained was good (R-squared = 0.897). From this work the chart shown in Figure 1 was derived. In this chart, the change in work of rupture reported in the Y-axis was calculated using an HVI elongation of 6% and HVI tenacity of 24 cN/Tex as bases. This graph illustrates the impact of elongation on work of rupture. Indeed, improving the tenacity while decreasing the elongation could lead to a decrease in work of rupture. For example, a variety A having a HVI tenacity of 28 cN/Tex and 4% elongation would have a work of rupture 15% lower than the base. In contrast, no improvement in fiber tenacity and an increase in elongation could result in a higher work of rupture value. As an example, a variety B with tenacity of 24 cN/Tex and an improved elongation of 8% would have work of rupture 23% higher than the base. Therefore, variety B would perform better in spinning and weaving than variety A. Nevertheless, variety A would receive a monetary premium because the current marketing system does not take elongation or work of rupture into account. It is, therefore, necessary to document the benefit for the cotton industry of cotton varieties having improved elongation and better work of rupture.

These results demonstrate the importance of fiber bundle elongation in the work of rupture of fiber bundles, which is critically important to processing performance. Therefore, there is need to breed new cultivars with improved work of rupture. This should result in lower fiber breakage when the cotton fibers are submitted to different mechanical stresses (ginning, carding, spinning, and weaving).

Materials and methods

Materials

Experiment 1: To test the repeatability of HVI tensile properties a representative sample of approximately 30 kg (70 pounds) was taken from three commercial bales. Each sample was homogenized according to the protocol used by the ICCSC (International Cotton Calibration Standard Committee) [7] to produce reference cottons. From the card web produced, samples were taken. The cotton samples were tested 6 times per day during a three day period on High Volume Instruments (HVI 900A, Uster, Knoxville, TN), with 10 replications for length, uniformity, tenacity, and elongation measurements and 4 replications for micronaire measurements.

Experiment 2: To determine the relationships between fiber properties (HVI and AFIS) and yarn tensile properties twenty one cultivars were selected. The cultivars were planted with two field replicates at the Texas Agricultural Experiment Station in Lubbock. The plots were stripper harvested and ginned with a 10 saw gin (seed cotton cleaners were used before the gin stand and lint cleaners after the gin stand). After ginning, a representative sample of lint was taken. The cotton samples were tested on High Volume Instruments (HVI 900A, Uster, Knoxville, TN), with 10 replications for length, uniformity, tenacity, and elongation measurements and 4 replications for micronaire measurements. They were also tested on the Advanced Fiber Information System (AFIS, Uster, Knoxville, TN), with 5 replications of 3,000 fibers. In this experiment, the spinning tests were performed on Suessen Fiomax 1000 ring spinning frame following the protocol outlined in Figure 2. The yarn count produced was 19.7 tex (30Ne). The yarns were tested on UT3 (400 meters per bobbin on 10 bobbins), on Tensorapid (10 breaks per bobbin on 10 bobbins), and on Scott Tester (10 skeins).

Experiment 3: To validate the findings of experiment 1, thirty two bales of cotton were selected based on their distinct physical properties. A representative sample of approximately 30 kg (70 pounds) was taken from each bale. Each sample was homogenized. The cotton samples were tested on High Volume Instruments (HVI 900A, Uster, Knoxville, TN), with 10 replications for length, uniformity, tenacity, and elongation measurements and 4 replications for micronaire measurements. They were also tested on the Advanced Fiber Information System (AFIS, Uster, Knoxville, TN), with 5 replications of 3,000 fibers. Then, spinning tests were performed on Suessen Fiomax 1000 ring spinning frame following the protocol outlined in Figure 2. The yarn count produced was 19.7 tex (30Ne). The yarns were tested on UT3 (400 meters per bobbin on 10 bobbins), on Tensorapid (10 breaks per bobbin on 10 bobbins), and on Scott Tester (10 skeins).

Experiment 4: It is important to verify that the conclusions drawn from Experiments 1 and 2 are valid over a large range of ring spun yarn counts. Therefore, four bales of cotton were selected based on their distinct physical properties. A representative sample of approximately 91 kg (200 pounds) was taken from each bale. Each sample was homogenized. The cotton samples were tested on High Volume Instruments (HVI 900A, Uster, Knoxville, TN), with 10 replications for length, uniformity, tenacity, and elongation measurements and 4 replications for micronaire measurements. They were also tested on the Advanced Fiber Information System (AFIS, Uster, Knoxville, TN), with 5 replications of 3,000 fibers. Then, spinning tests were performed on Suessen Fiomax 1000 ring spinning frame following the protocol outlined in Figure 2 (except that the cotton was combed to allow us to spin over a larger range of counts). The yarn counts produced were ranging from 18.5 tex to 7.6 tex (32Ne to 78Ne). The yarns were tested on UT3 (400 meters per bobbin on 10 bobbins), on Tensorapid (10 breaks per bobbin on 10 bobbins), and on Scott Tester (10 skeins).

Results and Discussion

Experiment 1:

Figures 3 and 4 clearly show that we can distinguish between the three strength and elongation levels. As shown Table 1, the CV% is about 2% for HVI strength for the three cottons. This translates into a range (maximum – minimum) of about 2 g/tex. For HVI elongation, the CVs are much higher and they tend to increase with increasing average elongation levels (CV% of 3.4 for an average elongation of 4.1%, 3.9 for an average elongation of 6.4%, and 6.5 for an average elongation of 9.0%). This translates into a range that also increases with increasing elongation (0.6, 0.8, and 2.0 for cottons 3213, 3289, and 3104 respectively). Therefore, the current HVI systems do not provide elongation measurements as repeatable as we would like. Nevertheless, the repeatability is good enough to distinguish between high, medium, and low elongation. Although this measurement is not perfect, it should suffice for breeding programs.

Experiment 2:

Stability of fiber and yarn tensile properties:

The variations of tensile properties among cultivars and field replications (different plots within the same field) are shown Figures 5 through 8. For the four charts the two field replications are very close. The variations between field replications from cultivar to cultivar follow each other. The linear regressions of field replication 1 against field replication 2 show that all R-squared values are statistically significant ($p<0.01$). For HVI, the R-squared values are 0.780 and 0.914 for fiber tenacity and fiber elongation respectively while for yarn tenacity and yarn elongation the R-squared values are 0.940 and 0.700 respectively. This reveals that these fiber and yarn parameters are not very sensitive to the environment; therefore, they are probably quite heritable (broad sense heritability) as previously mentioned by [5].

Meredith [8] reported that "the work of rupture is represented by the area enclosed by the stress-strain curve and the strain axis and would be half the product of breaking load and breaking extension if Hooke's law were obeyed". From his research he concluded that the work of rupture of individual cotton fibers comply with Hooke's law. The major difference between our work and Meredith's work is that we determined the tensile properties on fiber bundles (HVI bundles and yarn) rather than on single fibers. Thus, we are dealing with more complex systems where multiple fibers interact within the yarn. Nevertheless, examining the relationship between the product yarn elongation * yarn tenacity and the measured work is of interest (Figure 9). The coefficient of determination is very high (R-squared = 0.954) revealing a near perfect linear relationship. It means that there is a direct effect of both yarn elongation and yarn tenacity on the work of rupture. If one parameter increases while the other is constant, the work of rupture will increase. Therefore, to improve yarn performances the breeder should work on both yarn elongation and yarn strength which is practically unfeasible due to the cost and the quantity of raw material needed for spinning. Therefore, the solution lies in predicting these two parameters from fiber data. Obviously it is unlikely that fiber elongation or fiber strength would translate directly into yarn elongation or yarn strength. The friction forces between the fibers in the yarn should also have an impact on yarn properties. Among the most important fiber properties that may have an impact on fiber friction we could hypothesize that fiber length, fiber length distribution, and specific surface would be the most important.

Relationships between HVI fiber properties and yarn tensile properties

Using Statistica software [9], forward stepwise multiple linear regressions were performed between yarn strength, yarn elongation (dependent variables) and HVI fiber properties (independent variables).

As expected a good prediction of yarn strength can be achieved by using HVI strength, Upper Half Mean Length (UHML) and the Uniformity Index (Yarn Strength = 13.56 + 21.08 UHML + 0.225 Strength – 0.343 UI%, Adjusted R-squared = 0.900, $F(2, 39) = 124.01$, $p<0.00001$, Standard error of estimate = 0.607). It means that better is the UHML and the fiber strength better will be the yarn strength if the fiber length distribution is good (high Uniformity Index). Yarn elongation can also be predicted using HVI elongation and UHML (Yarn Elongation = -1.277 + 0.466 Elongation + 4.094 UHML, Adjusted R-squared = 0.844, $F(2, 39) = 111.73$, $p<0.00001$, Standard error of estimate = 0.175) (Figure 10). It means that better is the UHML and the fiber elongation better will be the yarn elongation. Therefore, breeding for cottons with longer and more uniform fibers as well as improved fiber strength and elongation will lead to better yarn work-to-break.

Relationships between AFIS fiber properties and yarn tensile properties

Forward stepwise multiple linear regressions were performed between yarn strength, yarn elongation (dependent variables) and AFIS fiber properties (independent variables). A good prediction of yarn strength can be achieved by using AFIS mean length by weight (L(w)), Standard fineness (Hs), and Maturity Ratio (MR) (Yarn Strength = 11.67 + 12.296 L(w) - 0.1147 Hs + 15.409 MR, Adjusted R-squared = 0.938, $F(2, 39) = 208.1$, $p<0.00001$, Standard error of estimate = 0.478) (Figure 11). It means that lower is the fiber diameter and better is the mean length and the maturity ratio, better will be the yarn strength. It is of interest to note that the yarn prediction is better with AFIS than with HVI, even though the AFIS does not measure fiber strength. Mature and fine cotton fibers are essential qualitative characteristics if one wants to better understand the facility of rupture of fibers when they are subjected to stress. It is intuitively obvious to hypothesize that immature fibers (having a thin, poorly developed secondary wall) will be fragile. Thus, they are likely to break during multiple mechanical stresses involved in transforming the fibers from the field to the yarn [10]. In addition, low fiber diameter (i.e., low standard fineness) means that for a given yarn count and fiber maturity level, more fibers could be packed in the structure of the yarn increasing the friction forces between fibers and therefore yarn strength. Nevertheless, even if the presence of L(w), Hs, and MR in the prediction equation is logical it is somewhat surprising to reach such a high R-squared value. An hypothesis to explain this result is that there is very little variation in the structure of the cellulose itself in the Upland germplasm tested.

Experiment 3:

On an independent set of cottons the same type of relationships was found. The best single predictor of yarn elongation is fiber elongation with a coefficient of correlation of 0.801 (highly significant) while the best single predictor of yarn strength is standard fineness with a coefficient of correlation of -0.918 (highly significant). When using the prediction equations stated in Experiment 1 and applying them to Experiment 2, the coefficients of determination for yarn elongation and yarn tenacity are 0.687 and 0.879 respectively, generally confirming the results of Experiment 2 (These results are highly approximate because the spinning conditions in both experiments were not exactly the same).

Experiment 4:

Figures 12 and 13 show that there are no interactions between the yarn tenacity or the yarn elongation readings and the yarn counts. Obviously the intercepts are different but not the slopes (confirmed with the statistical analysis shown in Tables 2 and 3. Therefore, we can expects similar rankings of the cultivars for any yarn count (within the spinable range for that cultivar).

Conclusions

Cotton breeding programs must deliver fibers that perform better in textile manufacturing in order to compete effectively with the various man-made fibers and with international growths of cotton. While the improvement of fiber tenacity has been for many years the focus of these programs, elongation has not been included because calibration cottons are lacking. Yet, the work of rupture (of a bundle of fibers or a yarn) is critically important and is determined by both tenacity and elongation. In this study, we demonstrated that a combination of fiber properties could provide good estimates of yarn elongation and yarn strength, using ring spun yarns over a large range of counts. Yarn elongation could be estimated from HVI elongation and HVI UHML (R-squared = 0.844) while yarn strength could be estimated from AFIS Mean Length by weight, AFIS Standard Fineness, and AFIS Maturity Ratio (R-squared = 0.938). Therefore, even though the HVI elongation measurement needs to be perfected, the use of HVI tensile properties in breeding programs could lead to improved yarn quality and processing performance (from the gin to the shirt).

Acknowledgment

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Literature cited

1. May, O.L. and Jividen, G.M., Genetic Modification of Cotton Fiber Properties as Measured by Single and High Volume Instruments, *Crop Sci.* **39**, 328-333 (1999).

2. Meredith, W.R., Culp, T.W., Robert, K.Q., Ruppenicker, G.F., Anthony, W.S., and Williford. J.R., Determining Future Cotton Variety Fiber Quality Objectives, *Textile Res. J.* **61(12)**, 715-720 (1991).

3. Meredith, W.R, Minimum Number of Genes Controlling Cotton Fiber Strength in a Backcross Population, *Crop Sci.* **45**, 1114-1119 (2005).

4. Backe, E.E., The Importance of Cotton Fiber Elongation on Yarn Quality and Weaving Performance, 9th Engineered Fiber Selection System Conference Proceedings, Cotton Incorportaed, Cary, NC, 1-13, 1996.

5. May, O.L., and Taylor, R.A. Breeding Cotton with Higher Yarn Tenacity, *Textile Res. J.* **68(4)**, 302-307 (1998).

6. Benzina H., E. Hequet, N. Abidi, J-Y. Drean, O. Harzallah. Using Fiber Elongation to Improve Genetic Screening in Cotton Breeding Programs. Textile Research Journal, in press.

7. USDA. 1999. International Calibration Cotton Standards program. Organization and operating procedures. USDA-AMS, Cotton Program, Memphis, TN, March 1999.7.

8. Meredith, R. The tensile behavior of raw cotton and other textile fibers. J. Textile Inst., 36, T107-T-130, 1945.

9. StatSoft, Inc. (2007). STATISTICA (data analysis software system), version 8.0. **www.statsoft.com**.

10. Hequet E., B. Wyatt, N. Abidi and D.P. Thibodeaux. 2006. Creation of a set of reference material for cotton fiber maturity measurements. Textile Research Journal, 76(7) 576-586.

Table 1. Basic statistics on the three ITC HVI tensile properties standards

Bale ID		Strength	Elongation
3104	**Minimum**	24.9	8.3
	Maximum	26.7	10.3
	Range	1.8	2.0
	CV%	1.9	6.5
3289	**Minimum**	27.7	6.1
	Maximum	29.8	6.9
	Range	2.1	0.8
	CV%	2.3	3.9
3213	**Minimum**	30.5	3.8
	Maximum	32.7	4.4
	Range	2.2	0.6
	CV%	1.8	3.4

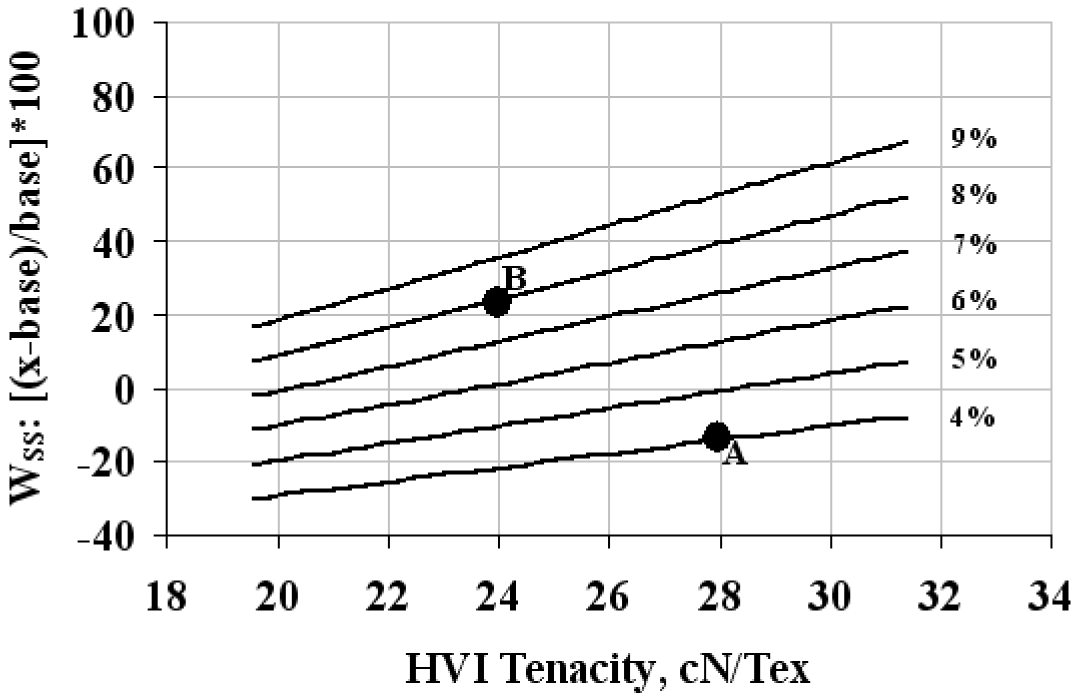
Table 2. Regressions yarn tenacity vs. yarn count

Bale ID		Coefficient	-95% Conf. Lmt.	+95% Conf. Lmt.
3406	**Intercept**	6.42	5.88	6.97
	Slope	-0.0275	-0.0373	-0.0118
	R^2	0.954		
3407	**Intercept**	7.25	6.50	8.00
	Slope	-0.0312	-0.0445	-0.0178
	R^2	0.940		
3423	**Intercept**	9.24	8.56	9.92
	Slope	-0.0394	-0.0515	-0.0274
	R^2	0.921		
3428	**Intercept**	7.97	7.31	8.64
	Slope	-0.0288	-0.0407	-0.0169
	R^2	0.941		

Table 3. Regressions yarn elongation vs. yarn count

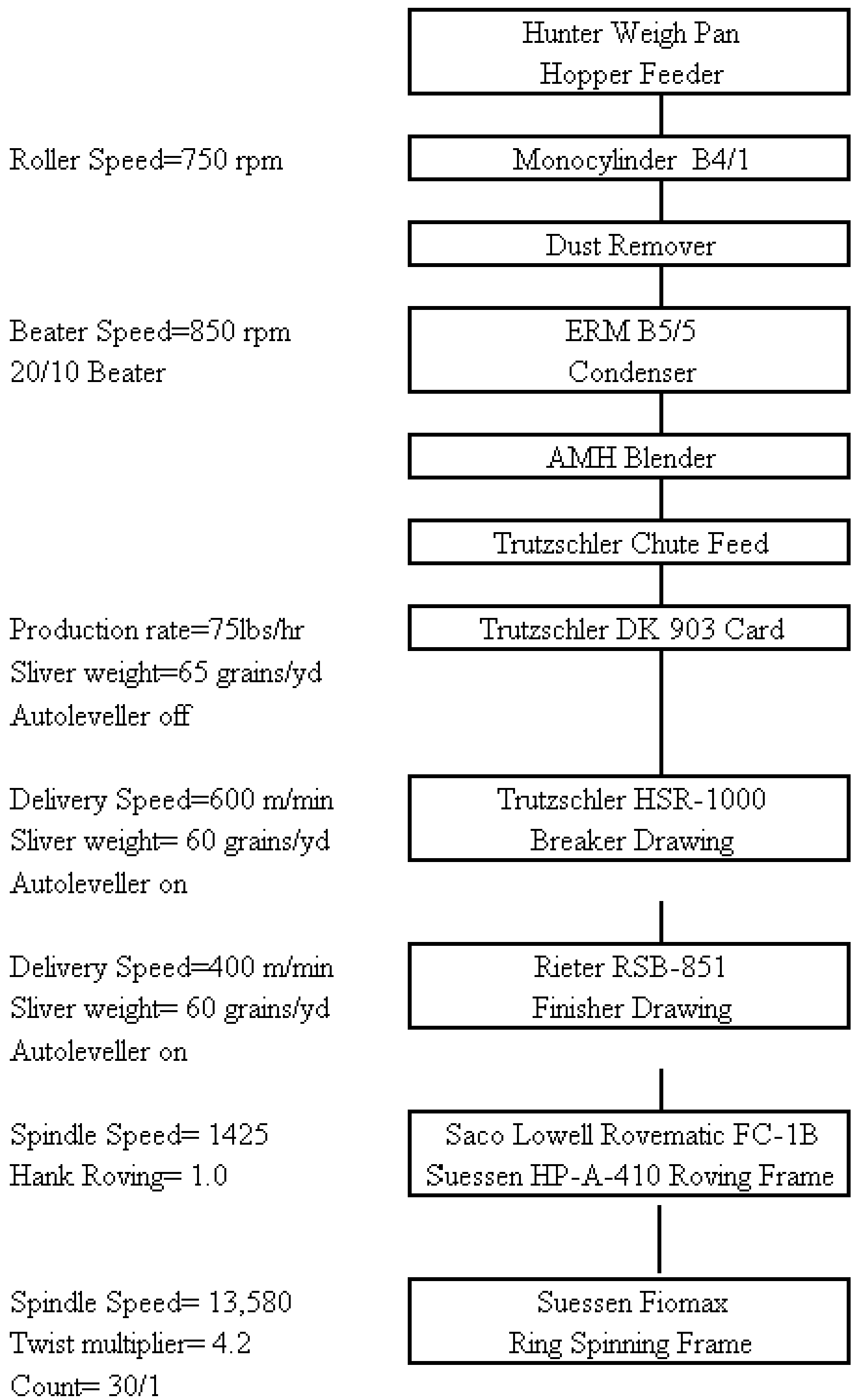
Bale ID		Coefficient	-95% Conf. Lmt.	+95% Conf. Lmt.
3406	**Intercept**	19.22	18.60	19.83
	Slope	-0.0707	-0.0817	-0.0597
	R^2	0.798		
3407	**Intercept**	18.83	18.13	19.53
	Slope	-0.0735	-0.0859	-0.0611
	R^2	0.730		
3423	**Intercept**	17.60	16.82	18.39
	Slope	-0.0675	-0.0814	-0.0535
	R^2	0.842		
3428	**Intercept**	18.68	18.10	19.25
	Slope	-0.0585	-0.0688	-0.0482
	R^2	0.744		

Figure 1.



100
80
60
40
20
0
-20
-40
18
20
22
24
26
28
30
32
34
W_{SS}: [(x-base)/base]*100
HVI Tenacity, cN/Tex
9%
8%
7%
6%
5%
4%
A
B

Figure 2.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Hopper Feeder
Roller Speed=750 rpm
Monocylinder B4/1
Dust Remover
Beater Speed=850 rpm
20/10 Beater
ERM B5/5
Condenser
AMH Blender
Trutzschler Chute Feed
Production rate=75lbs/hr
Sliver weight=65 grains/yd
Autoleveller off
Trutzschler DK 903 Card
Delivery Speed=600 m/min
Sliver weight= 60 grains/yd
Autoleveller on
Trutzschler HSR-1000
Breaker Drawing
Delivery Speed=400 m/min
Sliver weight= 60 grains/yd
Autoleveller on
Rieter RSB-851
Finisher Drawing
Spindle Speed= 1425
Hank Roving= 1.0
Saco Lowell Rovematic FC-1B
Suessen HP-A-410 Roving Frame
Spindle Speed= 13,580
Twist multiplier= 4.2
Count= 30/1
Suessen Fiomax
Ring Spinning Frame

Figure 3: Variations of HVI strength for three ITC standards cottons

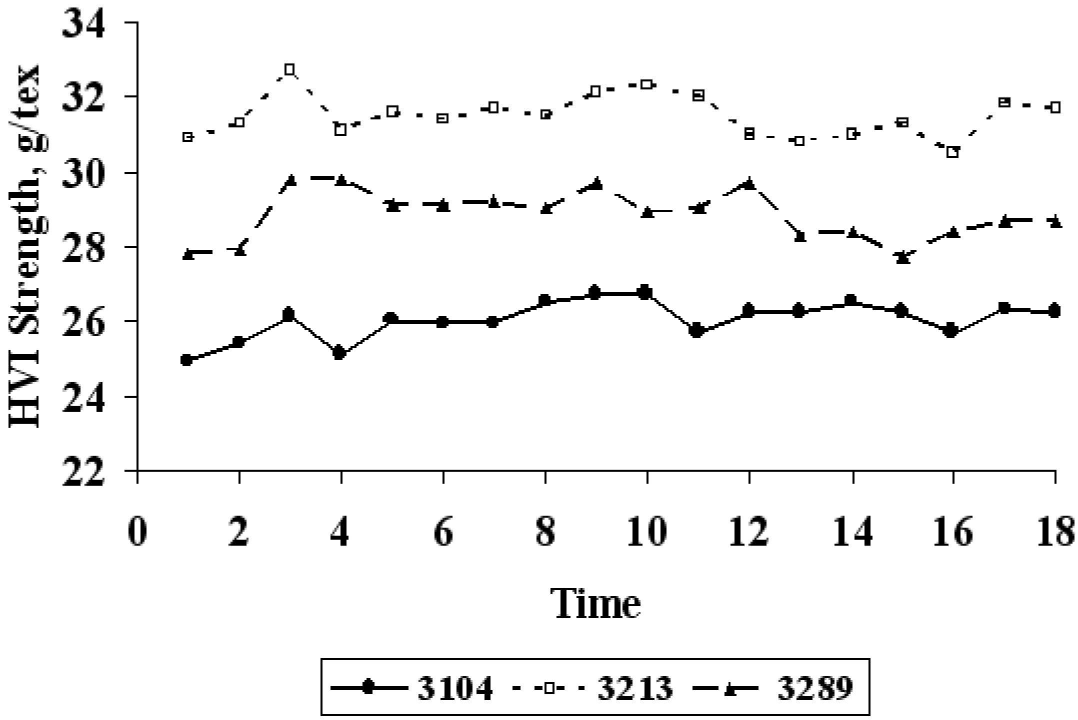


Figure 4: Variations of HVI elongation for three ITC standards cottons

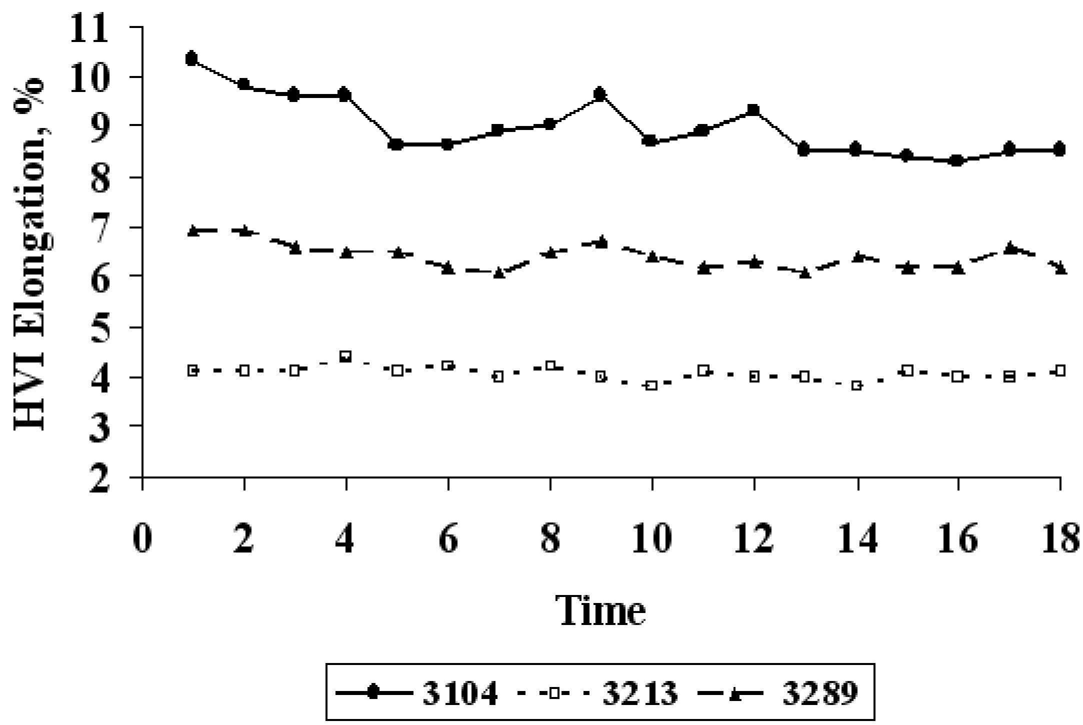
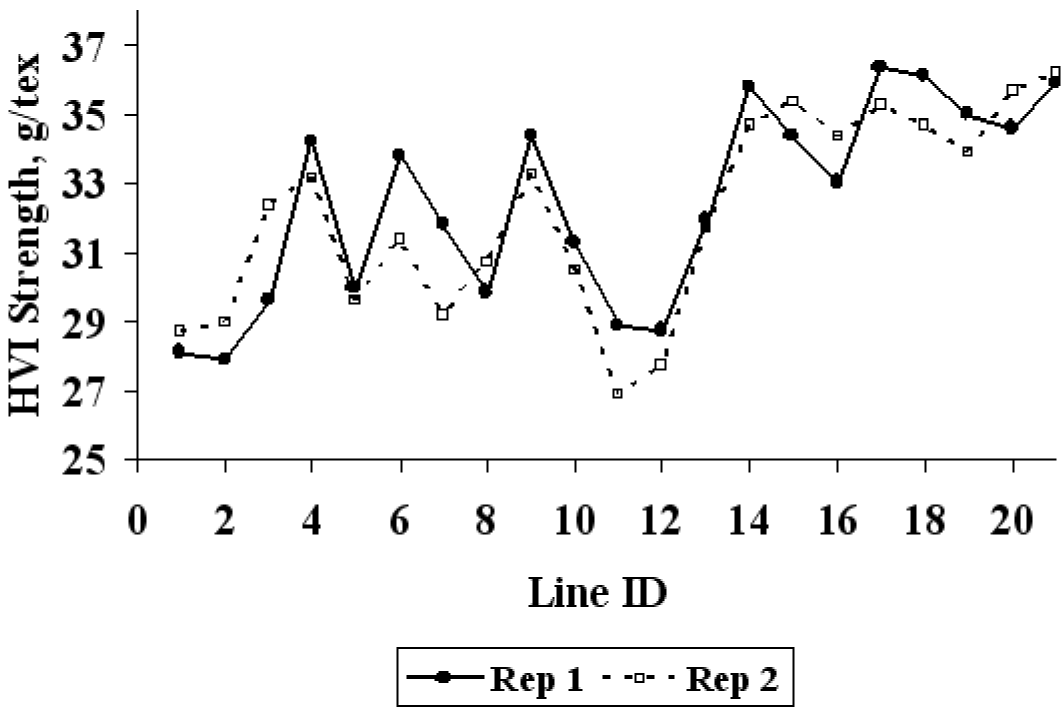


Figure 5: Variations of HVI strength among cultivars and field replications



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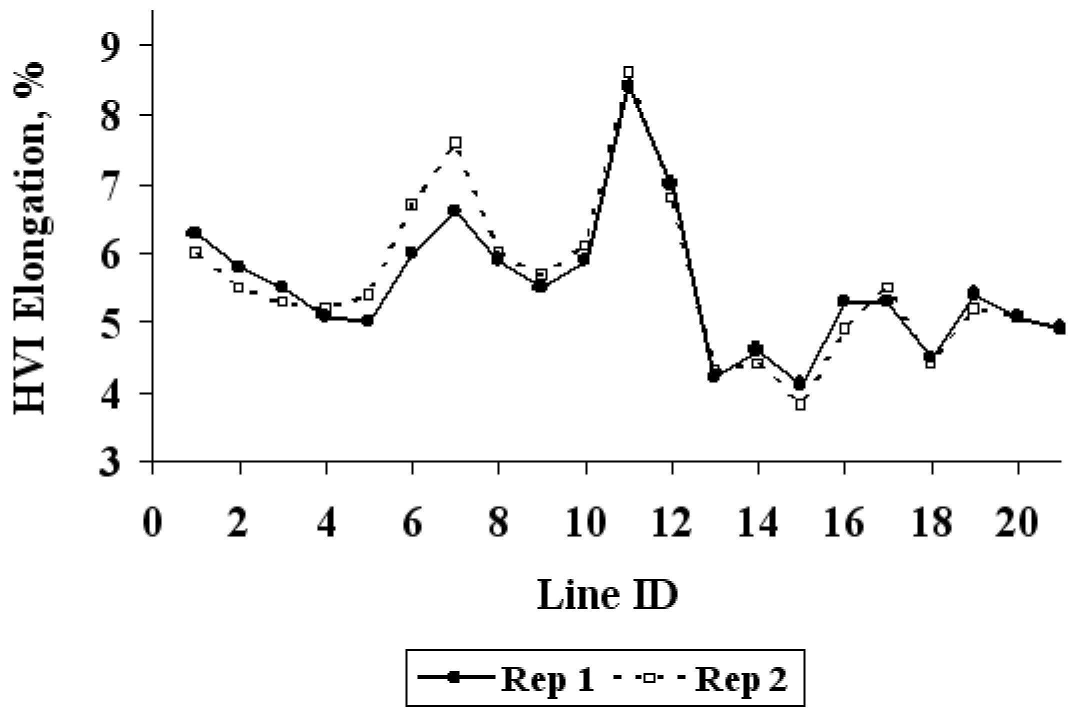

Figure 7: Variations of yarn tenacity among cultivars and field replications

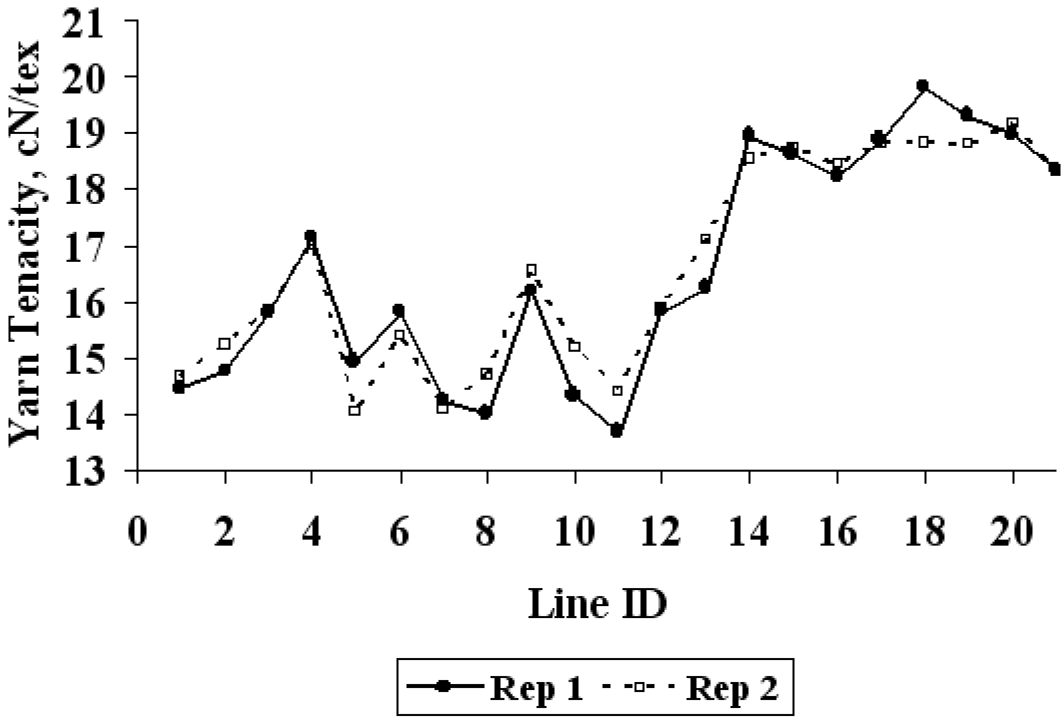

Figure 8: Variations of yarn elongation among cultivars and field replications

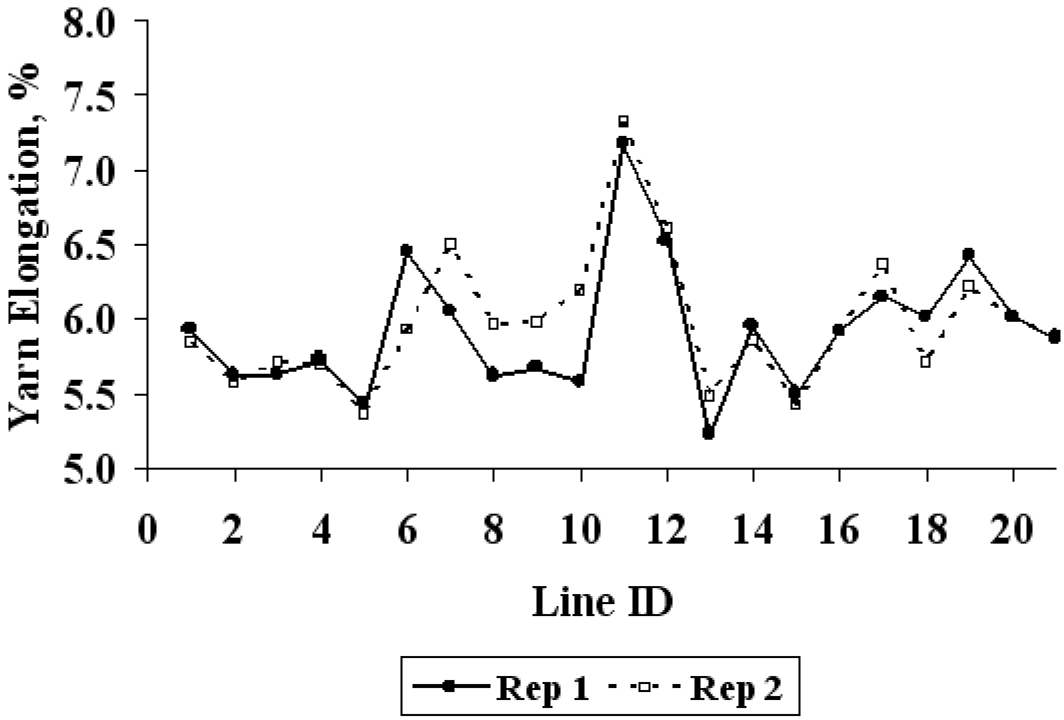

Figure 9: Yarn work of rupture (ring spun yarn 30Ne) versus the product Tenacity * Elongation.

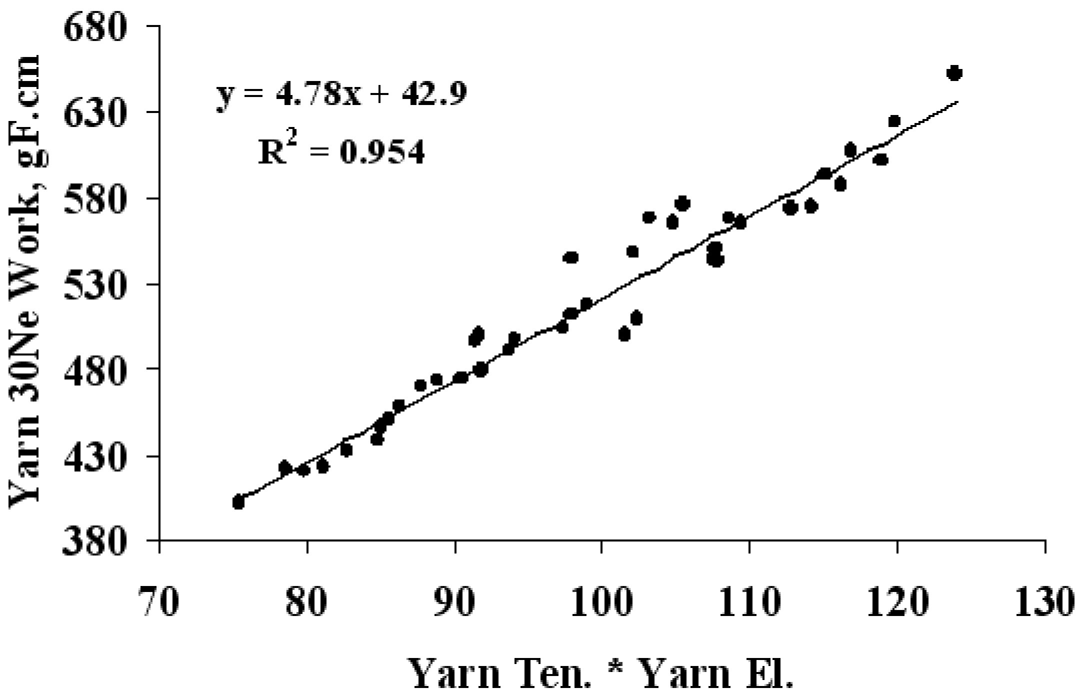

Figure 10: Yarn elongation – Predicted vs. Observed values (Yarn Elongation = -1.277 + 0.466 Elongation + 4.094 UHML, Adjusted R-squared = 0.844)

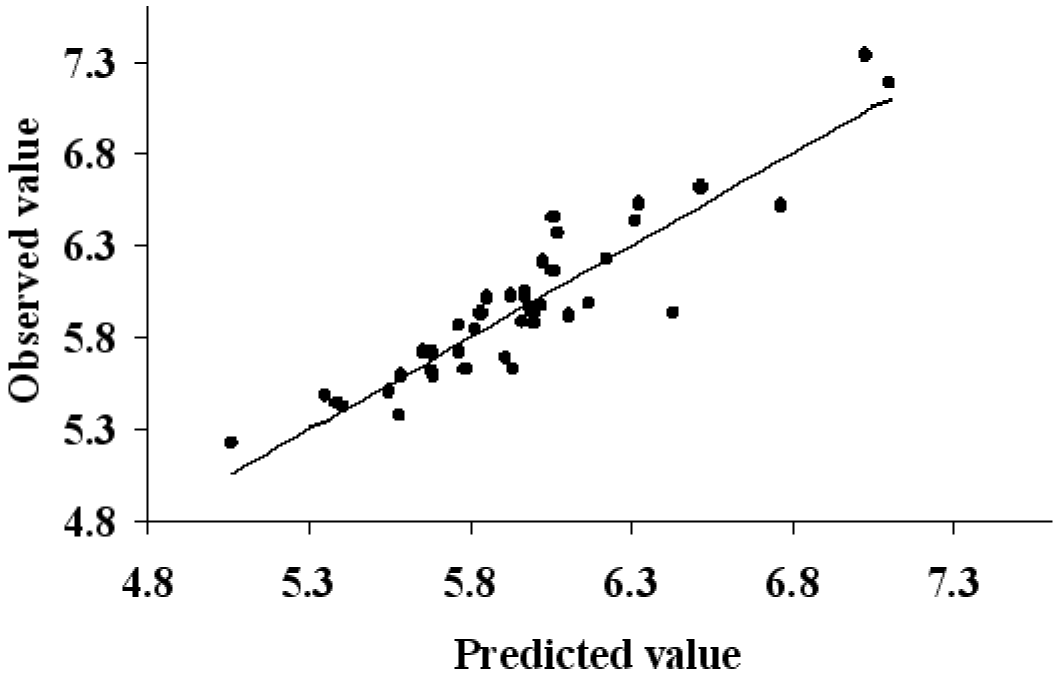

Figure 11: Yarn strength – Predicted vs. Observed values (Yarn Strength = 11.67 + 12.296 L(w) - 0.1147 Hs + 15.409 MR, Adjusted R-squared = 0.938).

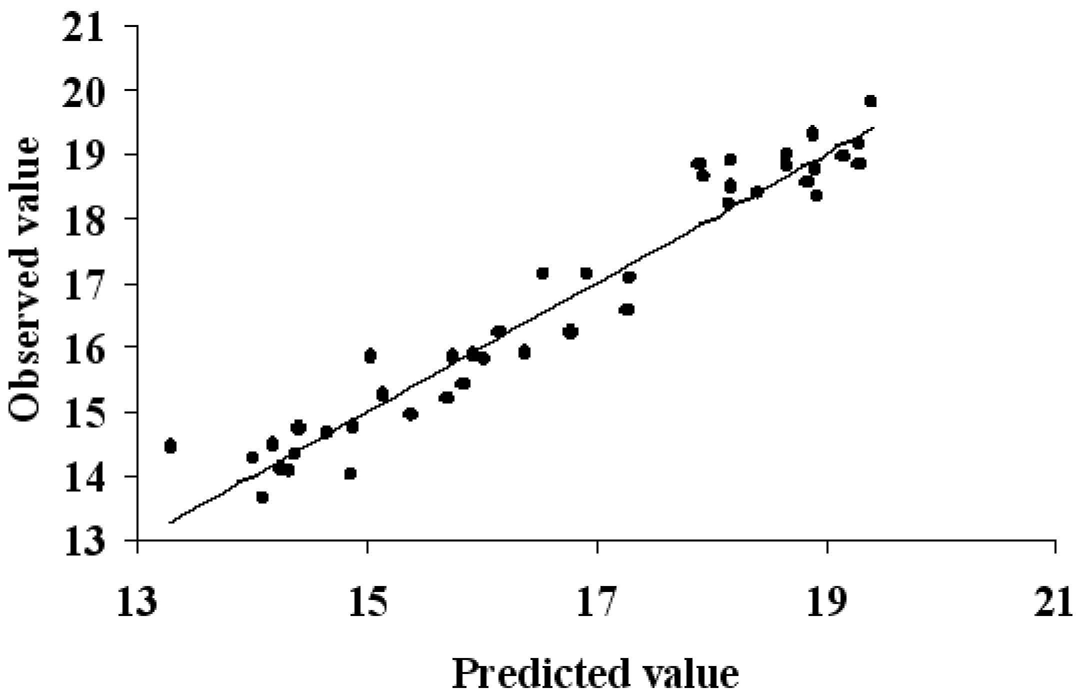

Figure 12: Evolution of yarn tenacity over a range of yarn counts for selected bales

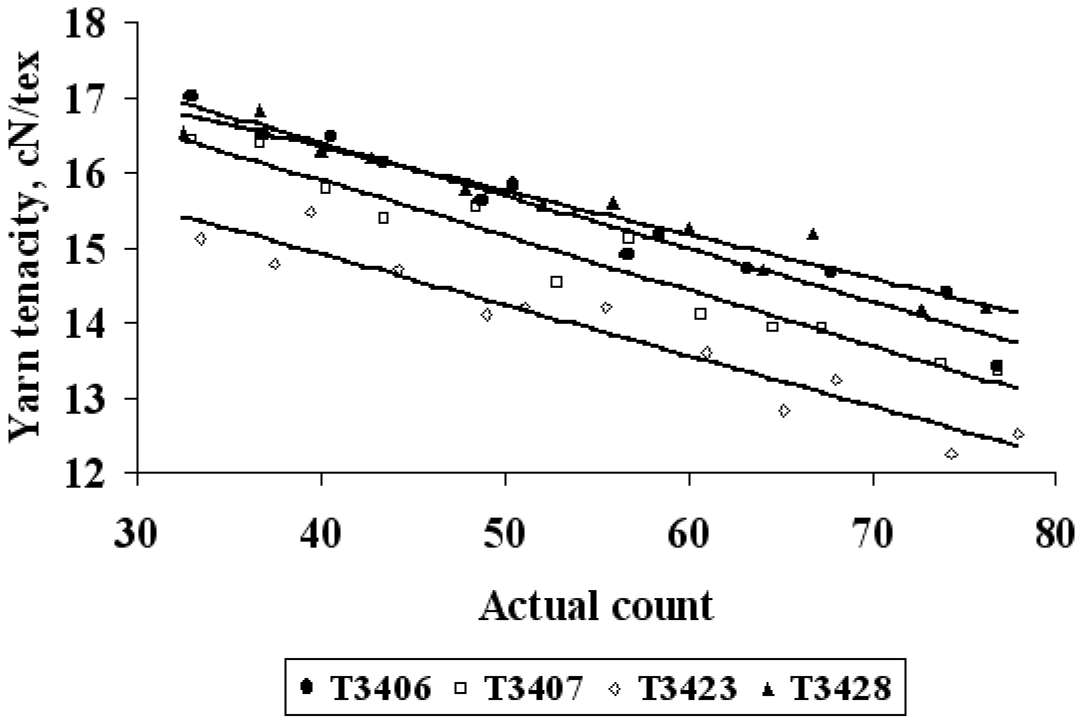

Figure 13: Evolution of yarn elongation over a range of yarn counts for selected bales