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Effects of Cropping System (Organic and Conventional) on the Fiber Quality Index, Spinning Consistency Index and Multiplicative Analytic Hierarchy Process of Cotton (*Gossypium hirsutum* L.)

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Abstract

Markets for organically produced high quality cotton (*Gossypium hirsutum* L.) are projected to increase. Field experiments were conducted in Palamas, Karditsa in Central Greece, to compare the effects of two cropping systems on fiber quality of three cotton cultivars. The experiments, conducted during three years, were laid out in a split plot design with four replicates, two main plots (organic and conventional system) and three sub-plots (cotton cultivars). Findings suggest that fiber quality index (FQI), spinning consistency index (SCI) and multiplicative analytic hierarchy process (MAHP) are three indices that could be integrated in a useful protocol for the evaluation of different cropping systems for cotton cultivation. In particular, our results indicate that in general there was not any superiority of conventional compared to the organic cropping system regarding fiber quality as shown by the above mentioned indices. Regarding the length of the cotton fiber, this was positively correlated with micronair and the uniformity index of the cotton fiber. The organic system resulted to higher values of SCI than the ones of the conventional (1547.9 and 1522.3, respectively). The present 3-years study shows that organic cultivation of cotton can ensure high fiber quality and this was clearly confirmed by means of the several important indices.

Keywords: *cotton crop, cotton quality, cultivars, fiber quality index, lint quality*

Introduction

In many countries, including Greece, cotton is one of the major industrial plants (Avgoulas *et al*., 2005) but is also one of the main manufacturing fiber plants (Papageorgiou *et al*., 2008). Cotton is the purest source of cellulose (content nearly 90%) and the most significant natural fiber. The molecular weight of cellulose is also highest among all plant fibers and it is characterized as highly crystalline (Gordon and Hsieh, 2007). All these properties give the cotton fiber a highly value and its secondary name as "White Gold". It has been shown that several agronomic practices may affect the quality parameters of the fiber (Bradow and Davidonis, 2000; Militký *et al*., 2004; Oosterhuis, 1994).

In the textile sector, many initiatives have been also taken and certification programs are available for every stage of textile production. These programs work quite successfully and provide their share towards environmental sustainability. Farming, processing and marketing organic cotton is also such an innovation. The niche market for organic cotton fiber shows a clearly increasing trend (Patsiali *et al*., 2014). It is well known that agricultural production in the last fifty years was strongly linked with the use of pesticides and synthetic fertilizers. This dependence on agrochemicals has resulted in many cases to the contamination of surface and underground water resources and no-target organisms. It is therefore necessary to use methods which will reduce the reliance on agrochemicals and ensure environmental sustainability (Bilalis *et al*., 2009; Sangakkara *et al*., 2004; Yusuff *et al*., 2007).

The latest technological requirements for fabric cotton fibers with improved specifications increased the global competition. This is closely related with practices regarding treatment (Blaise *et al*., 2005), sowing date (Pettigrew, 2002), chemical applications (Gormus, 2002) and irrigation (Constable and Hearn, 1981). However, the information regarding fiber quality of organic cotton is rather inadequate.

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Like all agricultural commodities, the value of cotton lint responds to fluctuations in the supply and- demand forces of the marketplace (Moore, 1996). In addition, pressure toward specific improvements in cotton fiber quality has been intensified as a result of technological advances in textile production and imposition of increasingly stringent quality standards for final cotton products. One of the first attempts to create aggregated criterion of cotton fiber quality was fiber quality index, FQI. Some additional indices widely used in marketing and certification of cotton are the spinning consistency index and the multiplicative analytic hierarchy process. The technological characteristics of cotton fiber used to calculate these indices are fiber length (mm), fiber length uniformity (expressed as uniformity index, *UI* [%]), fiber strength (known as bundle strength, *STR* [cN/tex]), fiber elongation ant break (*ELG* [%]), fiber fineness and maturity (expressed by micronaire reading (*MIC* [-]), short fiber content (*SF* [%]) and whiteness [expressed as percentage of reflectance (% Rd) and yellowness (+ b)].

The main objective of the present study was to evaluate the effects of the two major cropping systems (organic and conventional) and three cotton varieties on fiber quality by means of studying fiber quality index, premium discount index and proliferative analytical hierarchy process.

Materials and Methods

Experimental design

A cotton crop (*G. hirsutum* L.) was established in the area of Palamas, Karditsa in Central Greece, (39°25'54.35"N, 22°04'37.96"E). The soil was a clay loam (28.2% clay, 32.5% silt and 39.3% sand) with pH 7.11, organic matter 1.01%, EC 0.45 mS cm^{-1}, NO_3-N 16.3 mg kg^{-1}, P 15.8 mg kg^{-1}, K 257 mg kg^{-1}, Fe 77.4 mg kg^{-1} and Mg 1301 mg kg^{-1}. The experimental area is characterized by mild rainy winters and hot-dry summers. The mean values of meteorological data concerning air temperature and precipitation of the experimental site for the three years are presented in Table 1. The mean air temperature showed no significant differences across the three experimental periods of the experiment. The same was also true for average precipitation. However, there were some differences in the monthly rainfall distribution of the three periods. The experiment was set up in an area of 2496 m^2 according to the split plot design with two main plots (cultural systems: organic and conventional), three sub-plots (cotton varieties) and four replicates. The cotton varieties were 'Athena', 'Fandom' and 'Alexander'. The size of each sub-plot was 8 x 10 m. Sowing distances were 96 cm between rows and 5.6 cm between the plants in each row. Each plot consisted of 8 rows and measurements were taken from the two middle rows. In organic plots, vetch (*Vicia sativa* L. cv. 'Alexandros') was sown at the beginning of October 2007, 2008 and 2009 at a rate of 100 kg ha^{-1}. Before cotton sowing, the above-ground parts of fetch were removed, while roots were incorporated into the soil as green manure.

Sowing, irrigation and weed control

Cotton was sown by hand in a depth of 4 cm and approximate density of 156,000 plants ha^{-1} when soil temperature at a depth of 20 cm reached 15 °C. The field was sown on 30 April 2008, 15 April 2009 and 22 April 2010 at a rate of 28 kg ha^{-1}. Plant emergence started and completed 7 and 11 days after sowing, respectively.

The irrigation was started in mid-June and, until 20 days before harvest; the field area was irrigated six times. A drip irrigation system was set up on the plots. The drip system consisted of laterals with 20 mm diameter with in-line drippers and at 0.40 m distance. The drippers had a discharge rate of 4 l h^{-1} under an operation pressure of 1 atm. The duration of each irrigation was about 24 h and the amount that was used was a 30 m^3 of water per irrigation.

In conventional plots, weed control was mainly achieved by the use of the herbicide fluometuron 50% SC (Cotoran, 50 SC) in the recommended dose of 2.5 kg a.i. ha^{-1}. In the case of the organic plots, weeds were controlled by hand, with two hoeings being carried out.

Samplings, measurements and methods

Measurements were made on several technological characteristics of the cotton fiber. In particular, the following technological characteristics were analyzed: micronaire (fiber fineness), length (mm), strength (g Tex^{-1}), uniformity ratio (%), reflectance (whiteness, % Rd), yellowness (+b), elongation (%) and Short Fiber Index.

The High Volume Instrument (HVI) spectrum (by Zellweger Uster Inc) system was used to determine lint quality and particularly:

-The fiber length in millimetres was measured as 2.5% span length.

-The fiber uniformity (UI) was determined as the ratio of the mean length to the upper-half mean length expressed as a percentage.

-The fiber strength was determined as the force (g tex^{-1}) necessary to break the fiber bundle.

-The micronaire reading was taken as the fineness of the fiber expressed in standard micronaire units.

-The whiteness was expressed as percentage reflectance (% Rd), and the yellowness (+ b) represented the degree of cotton pigmentation.

-The elongation of the fiber of the cotton expressed as a percentage is directly linked to the ability of the yarn of cotton spinning.

-The short fiber content is an important indicator of the cotton quality and is defined as the percentage of short fibers that are less than half an inch (~1,3 cm).

The quality index of cotton fiber is directly connected with fiber strength, length, uniformity and fineness (expressed as MIC) as shown in equation (1):

$$FQI = LEN * UI * STR / MIC \quad (1)$$

Some other criteria are based on the regression models connecting fiber properties with parameters characterized spinning ability or quality of yarn, as previously described by Militký (1980) and Militký *et al.* (2004). The spinning consistency index (SCI) is connected with cotton HVI properties through regression model (Anonym, 1999), as shown in Equation (2):

$$SCI = -414.67 + 2.9*STR + 49.1*UHM + 4.74*UI - 9.32*MIC + 0.95*Rd + 0.36*b \quad (2)$$

Multiplicative analytic hierarchy process (MAHP) is a process which also assesses the fiber of cotton. It is influenced by the technological characteristics of the fiber and particularly strength, elongation, length, uniformity index, micronair and the short fiber index. According to Majumdar *et al.* (2005) this criterion is expressed by the following mathematical relationship:

$$MAHP = STR^{0.27} * ELG^{0.039} * LEN^{0.291} * UI^{0.145} / MIC^{0.11} * SFI^{0.145} \quad (3)$$

Statistical analysis

For conducting analysis of variance and comparisons of means, the software Statsoft 7 (Statsoft, Inc. 1996.) was used. The LSD test was used to detect and separate the mean treatment differences. Regression and correlation analyses were used to describe the relationships between growth parameters and fiber characteristics. All comparisons were made at the 5% level of significance. Apart from analysis of variance and comparisons of means, a combined analysis with time was conducted in accordance to the following model described by Büchse (2002):

$$X_{ijkl} = \mu + t_i + p_k + (tp)_{ik} + r_{kl} + d_{jkl} + v_j + (tv)_{ij} + (vp)_{ijk} + (tvp)_{ijk} + e_{ijkl} \quad (4)$$

where m = total average, t_i= the effect of the system i, p_k = the effect of the time k, r_{kl}= the effect of repetition l at time k, d_{jkl} = the error of the main piece of the i in iteration l at time k, v_j = the effect of a variety j, $(tp)_{ik}$, $(tv)_{ij}$, $(vp)_{ijk}$, $(tvp)_{ijk}$=effect of interactions and e_{ijkl} = error of subplots

For the significance test of the effect of each factor of this model, the denominator of the F test based on the theoretical composition of the mean square, assuming constant factors of variety and the system and random factor the year.

Results and Discussion

Fiber Quality Index (FQI)

It is worth noting that there was revealed a significant and positive correlation between most parameters determining fiber quality of cotton. More specifically, micronair and uniformity index of fiber in the organic subplots of the experiment were significantly correlated with the cumulatively length of the fiber. For the fiber quality index, a combined analysis for the three years of our experiments was also conducted. Our result showed that time was an important factor also affecting the fiber quality index (Table 2). Between the two cropping systems, there were not any statistically significant differences in the three years experiment.

Regarding the length of the cotton fiber, this was positively correlated with micronair and the uniformity index of the cotton fiber, in accordance with results from previous studies (Patsiali *et al*., 2014). The multiple regression between length, micronair and the uniformity index of cotton fiber in organic cropping system is expressed through the following equation Length =4.37+0.5*Micronair+0.27*Uniformity (R^2 = 0.75, $p < 0.0001$).On the other hand, the multiple regression between length, strength and uniformity index of cotton fibre in the conventional cropping system is expressed through the equation Length=1.73+0.22*Uniformity+0.26*Strength (R^2 = 0.68, $p < 0.0001$).

Spinning Consistency Index (SCI)

The results of the present study also revealed that time was an important factor regarding its effect on spinning consistency index (SCI) for cotton fiber as shown in Table 3. Moreover, statistically significant differences were observed between the two farming systems (organic and conventional) only during the second growing season (2008-2009) with the organic system (SCI=1547.9) showing higher values of SCI that the ones of the conventional (1547.9 and 1522.3, respectively). It has also to be noted that the mean values for SCI in the organic farming system were significantly higher than the relative values for the conventional system during the three years of the experiment.

Multiplicative Analytic Hierarchy Process (MAHP)

As mentioned above, a multiplicative AHP model has been proposed to determine the technological value of cotton. The proposed method uses a variant of the traditional FQI formula, and enhances the rank correlation between the technological value of cotton and yarn tenacity (Majumdar *et al*., 2005). Combined analysis as well as analysis of variance was conducted for multiplicative analytic hierarchy process for the three year experiment. It was revealed that time was a major factor that affected the process (Table 4). Our results confirmed that there were not any statistically significant differences between the two cropping systems in the three years experiment and is in full accordance with previous studies (Patsiali *et al*., 2014). However, in other studies it has been shown that some measures of lint quality (color grade and bale leaf rating) were lower in the organic than in the conventional treatment (Swezey *et al*., 2007).

The novelty of the present study is that by means of the three quality indices (FQI, SCI and MAHP), an accurate evaluation of several cropping systems can be achieved. In particular, the small differences between the two systems (organic and conventional) confirm the results of previous studies (Patsiali *et al*., 2014) and reveal the potential of further inclusion of the above-mentioned indices in a protocol for the evaluation of different cropping systems for cotton cultivation.

Conclusions

High yield potential of cotton crop remains the predominant consideration for the success of the crop; however, fiber properties are also important factors to be considered. Despite the magnitude of studies on fiber quality, very few studies have determined the effects of a cropping system on fiber quality characteristics of cotton over multiple years and cultivars. Throughout the use of several indices we can have a clear view concerning the evaluation of fiber characteristics. The present study confirms that FQI, SCI and MAHP are three indices that

Table 1. Meteorological data in the experimental site during experimental period (April-October)

	Apr	May	June	July	Aug	Sept	Oct
2008							
Mean Air Temperature (°C)	15.8	22.2	27.44	29.5	29.0	22.8	16.9
Precipitation (mm)	31.1	36.9	45.5	6.3	3.85	19.8	95.6
2009							
Mean Air Temperature (°C)	16.18	21.63	27.12	29.12	28.47	22.27	16.87
Precipitation (mm)	79.5	29.3	19.3	5.0	2.5	131.0	50.7
2010							
Mean Air Temperature (°C)	14.97	22.22	25.99	29.26	27.55	22.39	16.96
Precipitation (mm)	53.4	31.3	15.8	8.0	22.0	56.8	150.4

Table 2. Fiber quality index (FQI) for the three growing seasons in both cropping systems (organic and conventional) and mean values ('ns': not statistically significant for a significance level of $p < 0.05$)

Growing season	FQI			Mean
	2008	2009	2010	
Organic	22966.72 ns	17987.74 ns	19878.84 ns	20277.76 ns
Conventional	21484.01 ns	20386.95 ns	20852.95 ns	20907. 97 ns

Table 3. Spinning Consistency Index (SCI) for the three growing seasons in both cropping systems (organic and conventional) and mean values ('ns': not statistically significant; *: statistically significant for a significance level of $p < 0.05$)

Growing season	SCI			Mean
	2008	2009	2010	
Organic	1519.48 ns	1547.90*	1596.85 ns	1554.74*
Conventional	1435.21 ns	1522.30*	1504.11 ns	1487.20*

Table 4. Values for the Multiplicative Analytic Hierarchy Process for the three growing seasons in both cropping systems (organic and conventional) and mean values ('ns': not statistically significant for a significance level of $p < 0.05$)

Growing season	MAHP			Mean
	2008	2009	2010	
Organic	8.26 ns	8.92 ns	9.14 ns	8.77 ns
Conventional	8.77 ns	8.98 ns	9.13 ns	8.96 ns

could be integrated in a useful protocol for the evaluation of different cropping systems for cotton cultivation. Our results indicate that in general there was not any superiority of conventional compared to the organic cropping system. The present 3-years study shows that organic cultivation of cotton can ensure high fiber quality and this was clearly confirmed by means of the several important indices.

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