# Effects of soil, climate and cultivation techniques on cotton yield in Central Greece, using different statistical methods

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# Effects of soil, climate and cultivation techniques on cotton yield in Central Greece, using different statistical methods

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**Abstract –** This study aims to identify and quantify the relationship between the environmental and crop management variables and the cotton yield in the Thessaly plain in Central Greece. A total of 349 fields spread along the area were selected where cotton yield, soil and management data were measured for three consecutive growing seasons. A combination of statistical tools such as one-way and n-way analysis of variance (ANOVA), linear regression analysis and factor analysis was used for the identification and confirmation of the role of soil and management variables under different climatic conditions. ANOVA showed that soil order, topsoil and subsoil texture, carbonates, cultivar, previous uses of the sampling sites, defoliation and the spatial and temporal variation of the climate were significant for the yield ($P < 0.001$). Regression analysis confirmed the results of ANOVA and suggested that 50% of the yield variance is accounted for by soil variables, about the same percentage (47%) is accounted for by management variables, while soil and management variables together explain 65% of the yield variance. Factor analysis was applied on the data in two ways: (i) by including yield variable between the variables and (ii) by not including yield. Both analyses resulted in ten factors which were identified by the same groups of variables. Results from the first factor analysis suggested that 61% of the total yield variance is accounted for by the ten factors. Factors F1 and F2 explain about half of this variance while the factor F5 explains one third of it. Regression analysis on the factor scores calculated from the second factor analysis showed that factors F1, F2, F5 and F7 explain 41% of the total yield variance. In both analyses factor F1 is defined mainly from soil variables, while F2, F5 and F7 mainly from management variables.

**cotton yield / soil / management practices / statistical analysis / factor analysis**

**Résumé – Étude des effets du sol, du climat et des techniques de culture sur la production du coton en Grèce centrale, utilisant différentes méthodes statistiques.** L'objectif de cette étude était de déterminer et quantifier la relation entre les variables de l'environnement et celles de la conduite de la culture sur la production du coton dans la plaine de Thessalie, en Grèce centrale. 349 champs répartis sur toute la région ont été choisis dans lesquels nous avons mesuré pendant trois années consécutives la production de coton et les variables qui caractérisent sa culture et les sols. Trois méthodes statistiques ont été utilisées (analyse de variance à un et plusieurs critères, régression linéaire et analyse

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factorielle) pour identifier et confirmer l'effet des techniques culturales sous différentes conditions climatiques. L'analyse de variance (ANOVA) a montré que la catégorie de sol, la composition mécanique de la couche superficielle et celle du sol en profondeur, la teneur en carbonates, le cultivar, les précédents culturaux, la défoliation et les variations spatio-temporelles du climat ont un effet significatif ($P < 0.001$) sur le rendement. La régression linéaire a confirmé les résultats des ANOVA et suggéré que 50 % de la variation du rendement est liée aux variations de sol tandis que le même pourcentage (47 %) serait dû aux variables de conduite de culture ; l'ensemble ces deux groupes de variables expliquent 65 % de la variation du rendement. L'analyse factorielle a été réalisée de deux manières différentes : (i) en incluant les données de rendement parmi les variables et (ii) en ne les incluant pas. Dans les deux analyses, dix facteurs ont été mis en évidence, identifiés par le même groupe de variables. La première analyse montre que 61 % de la variance totale du rendement est représentée par les 10 facteurs. F1 et F2 expliquent la moitié de cette variance tandis que F5 en explique le tiers. La régression réalisée sur les facteurs extraits par la seconde analyse a montré que les facteurs F1, F2, F5 et F7 expliquent 41 % de la variance totale du rendement. Dans les deux cas le facteur F1 est déterminé principalement par les variables de sol, alors que F2, F5 et F7 le sont par celles liées aux techniques culturales.

**coton / rendement / sol / techniques culturales / analyses statistiques / analyse factorielle**

## 1. Introduction

Cotton production has always been a capital-intensive land use in Greece. The crop is grown on some 200 000 ha, of which 75 percent are irrigated. Cotton is particularly important in the Thessaly plain where it covers 54% of the total cultivated area.

The cotton crop is a perennial plant that is grown commercially as an annual. It is a continuously growing crop, that is, flowering and boll development take place at the same time as stem elongation and leaf formation as long as the weather conditions allow.

Its biological cycle lasts 140–210 days depending on the cultivar, the soil and the climatic conditions. Medium textured soils rich in organic matter are the most suitable for cotton [15]. The climate affects the growth rate, the rate of assimilation and it controls the boll-maturation. Low temperatures and high amounts of rain during the sowing period result in the delay of emergence and consequently in the delay of harvest with the danger of destruction of the cotton yield from the usual rain during the harvest (September–October). High temperatures during the summer can cause flowering buds and bolls to abscise and decrease the yield [7].

A great variety of studies have described the variability of cotton yield associated with soil and climatic variables. Cassman et al. [1] pointed out that in California cotton cultivars show considerable yield differences (15%–20%) on vermiculite soils where late-season potassium deficiency occurs. Pettigrew [22] found that potassium deficiency leads to increased specific leaf weight and leaf glucose levels in field-grown cotton, while Tiwary et al. [31] studied the relationship of soil properties to cotton yield on sodic Vertisols. Sawan et al. [24] identified the climatic factors (evaporation, humidity and temperature) affecting flower and boll production.

Also, several studies have indicated the effects of management practices on cotton yield. Craig et al. [2] reported that decreased population resulted in greater fruiting site production and fruit retention. Heitholt [9] studied the effects of floral bud removal on yield, yield distribution and yield components. Also, responses of cotton to different tillage systems are reported [26]. The effects of different rotation crops on soil quality and cotton yield have been addressed in several studies [10, 11, 17]. Some cotton experiments have lasted for a long period of time such as 100 years [4, 17, 29].

During the last twenty years the maximum cotton yield in Greece has remained rather stable, which might indicate that the yields obtained are not significantly different from the potential. The considerable year-to-year yield fluctuations, and the total crop failure for some years and places suggest that Greece lies close to the northern border of the cotton belt and that the potential for cotton production might be comparatively limited. It was therefore decided to investigate the basic factors which affect the yield.

The cotton yield is influenced by such factors as soil texture and fertility, length of growing season, cultivar, temperature, precipitation, insects, diseases and the rotation with other crops [7]. The effects of these variables on yield were studied in time and space using data that were collected from the Thessaly plain of Central Greece for three consecutive years. The data were obtained from cotton fields under real production conditions. The fields studied included a wide range of environmental conditions. Therefore, the available environmental variability and its effects were used and analysed in the place of explicit experimentation. Basic statistical analyses, linear correlation analysis as well as one-way and n-way analysis of variance [14], multiple linear regression analysis [3, 27] and factor analysis [6, 32] were used to analyse the data collected.

The goal of this study was: (a) to rank the soil variables which are included in the Greek soil maps according to their effect on cotton yield; (b) to study the effects of management practices and climate on cotton yield and; (c) to determine production functions describing the relationship between the resulting yield and the soil and management variables.

## 2. Materials and methods

### 2.1. Study area

The study was performed in cotton crop grown fields of the Thessaly plain. This plain extends over 500 000 ha in the central part of Greece and comprises the largest lowland formation of the country. The basement of the Thessaly plain is a part of the old crystalline massif, which extends to eastern and north-eastern Greece and is composed of gneiss, schist and marbles of Palaeozonic to Triassic age. The Pinios river and its tributaries make up the principal drainage network of the Thessaly plain.

The soils of the area are mainly classified as Alfisols, Inceptisols and Vertisols according to the Soil Taxonomy classification system [28] and an effort was made for the sampling sites to cover equally these soil orders. More specifically, the soil requirements for the selection of the sampling sites were: (a) that they belong to some given taxonomic classes and; (b) that they belong to only one mapping unit according to the Greek soil mapping system. This was achieved by choosing sampling sites of a relatively small area. Almost equal numbers of sampling sites from the Alfisols (36.1%), Inceptisols (32.7%) and Vertisols (31.2%) soil orders were collected. Additionally, the sampling sites of each soil order were chosen so as to belong to as many different mapping units that are found in the area as possible. The mapping units of the Greek soil mapping system are defined in terms of soil drainage, texture, erosion, carbonates, slope and the direction and the degree of soil genesis.

For three consecutive growing seasons (1993–1995), soil, climate, management and yield data were collected from a number of sampling sites of the Thessaly plain. In the first year, 124 sampling sites were selected. In the following year, the number of sampling sites was reduced to 119 and in the third to 106. This reduction was due to the rotation of cotton fields every 3–4 years with cereals, especially when the fields are full of weeds, which negatively affect the production. The study area and the areas of the sampling sites are shown in Figure 1.

The cotton crop grown in the sampling sites is *Gossypium hirsutum* L., cultivars 4S and of the American origin Acala (Zeta-2 and Zeta-5). These cultivars have always been recommended by the Greek Extension Services and widely grown by producers in Thessaly plain. The fields that were planted with cultivar 4S cover 61.6% of the total sampling sites while those planted with Acala (Zeta-2 and Zeta-5) cover 38.4% of the total.

The climate of Thessaly plain is Mediterranean with hot summers and cold winters. More precisely it is Continental Mediterranean [20, 21] with a combination of a continental temperature regime and a dry Mediterranean moisture regime. For the

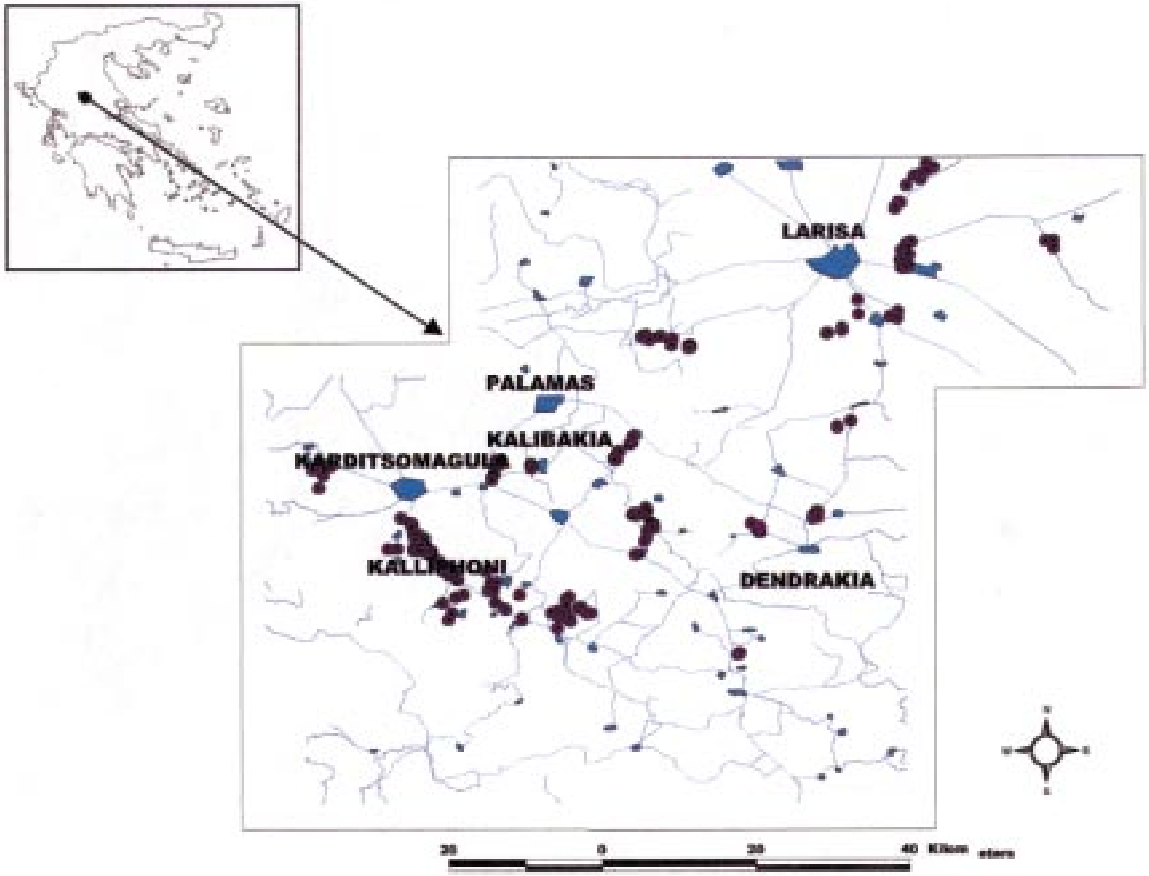


**Figure 1.** The study area and the sampling sites (●).

months from April to October, that are important for the cotton crop, the mean monthly temperature varies from 15 °C to 28 °C. July is the hottest month in the area. During this month, the mean maximum temperatures in the areas studied usually vary from 26 °C to 34 °C, while the mean minimum temperatures vary from 16 °C to 19 °C. The mean annual precipitation varies between 466 mm to 780 mm from east to west, while between the months of April to October precipitation varies between 160 mm to 316 mm, respectively.

For the assessment of the climatic conditions during the three years, data from six meteorological stations were used. These meteorological stations were selected from a network of sixteen stations of the Greek Cotton Organization [8] on the basis of the accuracy and the availability of their data, during the period of the study. Every sampling site was assigned to its nearest station. The positions of the six stations (Karditsomagoula, Larissa, Dendrakia, Palamas, Kalivakia and Kalifoni) are shown in Figure 1.

In the first year the mean maximum temperatures in July ranged from 36 °C to 41 °C (between the six stations), whereas during the next two years they never exceeded 38 °C. No extreme values in the minimum temperatures during the three years were observed. On the contrary, there were significant differences in the distribution of rain values between the three years and between the six stations. During the first year in some areas there was intensive rain (≈ 100 mm) for one week in the middle of April (which either delayed the sowing or caused re-sowing), while there was no rain during the summer. The second year was characterised by a small amount of rain during April (6 mm–13 mm) while significant amounts of rain during May and June (highest amount of the three years), positively affected the crop. During the third year, although the total amount of rain in the month of April was similar to that of the first year, it was uniformly distributed throughout the month. Rainfall during the month of October was at normal levels for all three years.

### 2.2. Data variables

For each sampling site a number of soil and crop management variables were measured and stored in the database of a geographical information system which was developed for the purposes of this study. Each sampling site was treated as a different entity for each cultivation year. Therefore data for 349 sampling sites was stored in the database.

The soil variables whose effects on the yield were studied in this paper are those that are included in the soil maps of Greece. The management variables used correspond to the usual cultural practices of the cotton in the area.

Attributing to nominal (qualitative) variables numerical codes, is a requirement for using these variables in regression analysis, which express a quantitative relationship between the variables. Original values were used for interval, ratio or ordinal (quantitative) variables. The variables whose values were stored in the database, their coding and their abbreviation symbols are:

(i) Cotton yield

– Yield: Cotton yield is expressed as tons per hectare.

(ii) Soil variables

– Texture: Texture of three depths 0–25 cm (TEX1), 25–75 cm (TEX2) and 75–150 cm (TEX3) was considered and expressed as percentage of clay. The textural class of each of the three depths is expressed, in the the soil maps of Greece, as an integer ranging from 0 to 5 whose meaning is given in Table I [34]. These integers (symbols) were transformed into percentages of clay using the following procedure. The textural classes that correspond to each numerical symbol define an area in the texture triangle [28]. The percentage of clay corresponding to the center of this area was assigned to the corresponding integer symbol. The integer symbols and the corresponding clay percentages are presented in Table I.

– Drainage (DRN): 1: Very well drained; 2: Well drained; 3: Moderately drained; 4: Somewhat poorly drained; 5: Poorly drained; 6: Very poorly drained.

– Erosion (ERO): 0: No erosion; 1: Slightly eroded; 2: Moderately eroded; 3: Very eroded; 4: Severely eroded.

– Carbonates (CAR): 0: No reaction throughout the soil profile; 1: Some reaction occurs deeper

**Table I.** The texture mapping symbols, the corresponding classes and percentages of clay.

| Mapping | Depth 0–25 cm | | Depth 25–75 cm | | Depth 75–150 cm | |
|---|---|---|---|---|---|---|
| Symbol | Texture class | % clay | Texture class | % clay | Texture class | % clay |
| 0 | Gravels > 60% | | Gravels > 60% | | Gravels > 60% | |
| 1 | S, LS | 5 | S, LS, SL, | 9 | S, SL, LS | 9 |
| 2 | SL | 10.5 | Si; SiL, L | 14.5 | L, Si, SiL | 14.5 |
| 3 | Si, SiL, FSL | 14.5 | CL, SiCL, SCL | 32.5 | More fine than L | 18.5 |
| 4 | SCL, CL, SiCL | 32.5 | C, SiC, SC | 60 | | |
| 5 | SC, SiC, C | 60 | | | | |

*Texture*: Si: Silt; SiL: Silty Loam; SiCL: Silty Clay Loam; SiC: Silty Clay; L: Loam; LS: Loamy Sand; C: Clay; CL: Clay Loam; S: Sand; SL: Sandy Loam; SC: Sandy Clay.; SCL: Sandy Clay Loam.

than 25 cm; 2: Slight reaction in the surface layer, while the reaction in the deeper sections is not considered; 3: Strong reaction in the surface layer, while the reaction in the deeper sections is not considered.

– Slope (SLO): Percent.

– Soil order (SOR): Soil order was expressed according to the Soil Taxonomy classification system [28]. In the regression analysis two dummy variables, Z1 and Z2, were used (Tab. II) for coding the variable soil order into the three classes (Alfisols, Inceptisols, Entisols) identified in the area [23].

(iii) Climatic variables

– Cultivation year: The integers 1, 2 and 3 were used for coding the three growing seasons 1993, 1994 and 1995 respectively.

– Local conditions: An integer number from 1 to 6 was used to identify each of the six areas to which the sampling sites belonged.

(iv) Management variables

– Re-sowing (RES): 1: True, 0: False.

– Cultivar (CUL): 1 for 4S, 0 for Acala (Zeta-2 and Zeta-5).

– Spacing out (SPO): Percent.

– Quantity of seed (QUS): Is expressed as kilograms of seed per hectare.

– Percentage of germination (PGE): Percent.

– Nitrogen (N): Kilograms per hectare in oxide form ($N\text{-}NO_3$).

– Phosphorus (P): Kilograms per hectare in oxide form ($P\text{-}PO_4$).

**Table II.** The coding of the three soil orders.

| Soil order | Z1 | Z2 |
|---|---|---|
| Alfisol | 1 | 0 |
| Inceptisol | 0 | 1 |
| Vertisol | 0 | 0 |

– Weed control before sowing (WCS): 1: True, 0: False.

– Weed control after emergence (WCE): 1: True, 0: False.

– Insect control for aphids sp. (ICA): Number of applications.

– Insect control for worms (ICW): Number of applications.

– Irrigation before germination (IBG): Number of applications.

– Irrigation after emergence (IAE): Number of applications.

– Defoliation (DEF): 1: False, 0: True.

– Previous use (PRU): 0: Two years cereals, 1: One year cereals, 2: One year cotton, 3: Two years cotton, 4: Three or four years cotton.

– Type of harvesting (TYH): 1: By hand, 0: Mechanised.

– Number of days between sowing and harvesting (DSH): Number.

### 2.3. Statistical analysis

The determination of the most significant variables among the system soil-climate-crop management that influence the cotton yield was carried out through a statistical analysis of the collected data. The methods used included basic statistical analyses (e.g. mean, variance, coefficient of variation), linear correlation analysis, one-way and n-way analysis of variance, regression analysis and factor analysis. The goal was not only to determine a production function describing the relationship between yield and all the possible combinations of the variables influencing it, but also to determine how the variables could account for the variance of yield between different areas and different years, as well as the mutual influences between these variables. A variety of different methods of statistical analysis were used for that purpose**.**

The statistical analysis was based on the assumption that soil varies between different areas, whereas climate varies between different cultivation years and different areas. In the case of crop management, the variation was expressed in terms of different cultivars and cultural practices used. These assumptions led to the definition of sub-populations for each variable and the use of separate statistical analyses for each one of these sub-populations.

One-way analysis of variance [14] plus least significance difference (LSD test) was used to test the differences in yield between areas with different soil order and between the three years of study.

Pearson correlation coefficients and the associated *P*-values were calculated to determine the tendency of change (if any) between yield and each one of the independent variables influencing it (e.g. clay content, quantity of fertiliser, etc.). The correlation coefficients were also used to investigate if the independent variables were inter-correlated.

N-way analyses of variance with yield as the dependent variable were carried out to examine the interaction effects. A very interesting use of the analysis of variance is the study of the changes of the influence of a variable on yield as more variables are entered into the analysis. The effects of an independent variable on yield are considered significant when the mean of the yield in each subclass of the independent variable differs from the grand mean of the yield. When more variables are entered into the analysis these differences change. The study of the changes was made through the Multiple Classification Analysis (MCA) [14].

Multiple regression analysis was used mainly to find structural relations and examine the complex multivariate relationships between yield and the independent variables. The contribution of one or more specific variables is assessed, taking into account the effect of the other variables in the regression equation [13]. In order to evaluate the influence of soil and management practices on yield, the independent variables used in the regression were those that describe each one of these production factors. Examination of the different production factors was done separately (separate regression). The selection and introduction of the independent variables for each equation was done using the forward stepwise selection method. The choice of the final equation for each case was based on: (a) the coefficient of multiple determination $R^2$; (b) the value of ratio F (F= regression sum of squares / residual sum of squares) and the significance level of this ratio which is used to test the statistical significance of the regression coefficients and; (c) the value of the T-test and the significance of this value, in order to test the significance of each independent variable.

Factor analysis, unlike regression analysis, does not require the determination of a specific form of relationship between the variables. Additionally, the problem of multicollinearity is eradicated and the fact that the results include all variables may facilitate the observation of structural relationships, the examination of qualitative and quantitative relations between variables and the identification of the main factors that influence the variance of yield. Factor analysis [6] leads to a reduction in the original number of variables. The original set of variables is reduced to a much smaller set of variables (extracted factors) which can be used as operational representatives of the constructs underlying the complete set of variables. The most important results of the factor analysis are: (a) the percentage of total variance explained by each factor (eigenvalue); (b) the percentage of variance of each variable explained by each factor (factor weighting); (c) the percentage of variance for each variable explained by all factors (communality) and; (d) the value of each factor for each sampling site (factor score). A relatively small number of factors that cumulatively explain a big portion of the total variance is a sign of a strong factor analysis model. High communality values for a variable are an indication that a high portion of the variance of that variable is related to the influence of the determined factors. Conversely, low communality values indicate that the determined factors have little influence over that variable. The variables with the highest weightings in each factor are used to identify that factor. We used the principal component solution [12] and the varimax rotation extraction.

## 3. Results and discussion

### 3.1. One-way analysis of variance

(i) Soil-yield relationship. The one-way analysis of variance and the least significant difference testing showed that the differences in the yield between the three soil orders are significant ($P < 0.001$). The Vertisol soils are more productive than the Inceptisol ones and the latter more productive than the Alfisol soils. The average yields of the three soil orders, Alfisol, Inceptisol and Vertisol are 2.43 t/ha, 2.88 t/ha and 3.20 t/ha respectively.

The texture class of the surface (0–25 cm) and the subsurface (25–75 cm) layers, which were expressed as percentages of clay, are the soil variables that affect the yield significantly. The analysis of variance showed that the averages of the yield of the four textural classes, which were determined according to the texture of the surface layer, demonstrate significant differences (Tab. III), whereas the correlation coefficient showed that a larger clay content percentage leads to a larger yield (Tab. IV). A similar increase of yield appears when the clay content rises in the depth 25–75 cm (Tab. III). In the soil depth 75–150 cm no correlation is found, since cotton is an annual crop whose root system does not exceed a depth of more than 80 cm.

The study of the relationship between carbonates and yield showed that a larger carbonate content (a stronger reaction), especially in the topsoil, is associated with a more productive cotton cultivation. Of course, a very large carbonate content in the topsoil lowers the productivity (Tab. III) due to the appearance of deficiencies and the restriction of assimilation of boron [25].

Drainage does not affect the yield since the cultivation period of cotton does not coincide with the wet months of the study area. Since data was collected only from flat areas it was not possible to study the effect of the slope on yield. Additionally, from the small number of the eroded sampling sites it can be concluded that erosion affects the yield negatively.

(ii) Cultivation year-yield relationship. The study of the average yields during the three cultivation years demonstrated that the first year

**Table III.** One-way analysis of variance on soil order, texture 0–25 cm, texture 25–75 cm and carbonates.

| Soil order | Yield (t/ha) | | Texture 0–25 cm Symbol–% clay | Yield (t/ha) | | Texture 25–75 cm Symbol–% clay | Yield (t/ha) | | Carbonates | Yield (t/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S. E. | | Mean | S. E. | | Mean | S. E. | | Mean | S. E. |
| Alfisol | 2.43 | 0.046 | 2–10.5 | 2.25 | 0.184 | 2–14.5 | 2.57 | 0.114 | 0 | 2.47 | 0.050 |
| Inceptisol | 2.88 | 0.067 | 3–14.5 | 2.49 | 0.048 | 3–32.5 | 2.44 | 0.054 | 1 | 2.76 | 0.069 |
| Vertisol | 3.20 | 0.049 | 4–32.5 | 2.80 | 0.091 | 4–60 | 3.02 | 0.036 | 2 | 3.31 | 0.053 |
| | | | 5–60 | 3.12 | 0.049 | | | | 3 | 2.77 | 0.096 |
| $F_{value} = 51.96$ | $P < 0.001$ | | $F_{value} = 26.30$ | $P < 0.001$ | | $F_{value} = 32.21$ | $P < 0.001$ | | $F_{value} = 36.78$ | $P < 0.001$ | |

**Table IV.** Correlation coefficients between yield and clay percentages of three depths 0–25 cm, 25–75 cm and 75–150 cm.

| | % clay 0–25 cm | % clay 25–75 cm | % clay 75–150 cm |
|---|---|---|---|
| Yield (t/ha) | r = 0.43 ($P < 0.001$, n = 349) | r = 0.36 ($P < 0.001$, n = 349) | r = 0.03 ($P < 0.05$, n = 349) |

(124 sampling units) had the lowest productivity, 2.53 t/ha whereas the following two years (119 and 106 sampling sites respectively) had average yields that were 2.93 t/ha and 3.02 t/ha respectively.

The one way analysis of variance and the least significant difference tests ($P < 0.05$) showed that the differences in the yield between the last two years are not significant whereas the differences between the first year and the second and third year respectively, differ significantly.

The study of the climatic conditions during the first growing season explains the observed differences. The dry conditions associated with the intense heatwave of the summer and the ineffectiveness in controlling the infection by aphids sp. adversely affected the yield of the first year. Also the intense rain during the sowing period of the first year (middle of April) delayed sowing and consequently harvest, and resulted in the destruction of part of the yield due to the (usual) rains of October.

The normal climatic conditions of the two last years by contrast led to similar yields both years, which reveals that, the effect of other variables (e.g. soil orders, cultivars) cancelled out, their effect becomes statistically insignificant. Therefore, the variance of the yield between the three years was due to differences in climatic conditions.

(iii) Local conditions-yield relationship. The study of spatial variations of yield revealed that there were significant differences in the average yield between the six areas to which the sampling sites belonged (Tab. V). The most productive areas were Kalivakia and Dendrakia, and these were followed in diminishing yield order by Larissa, Palamas, Karditsomagoula and Kalliphoni. The observed differences between the areas reveal different productivity dynamics, possibly due to the observed climatic variations between the six areas.

The study of each soil order separately, demonstrated that the sampling sites with soil orders Inceptisols ($F_{value} = 7.765$, $P < 0.001$) and Vertisols ($F_{value} = 4.462$, $P = 0.002$) presented significant differences in the mean yield between the six areas while Alfisols did not ($F_{value} = 1.1891$, $P = 0.116$). From these results it can be concluded that favourable climatic conditions did not increase yield in sampling sites with Alfisol soils. This suggests the necessity of studying the mutual influence of climate and soil on yield.

(iv) Crop management-yield relationship. There were significant differences of yield ($P = 0.009$) between cultivars. The 4S cultivar was less

**Table V.** Mean yield (t/ha) and standard error (S. E.) of the six areas for each cultivation year and one-way analysis of variance.

| | Yield (t/ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1993–1995 | | 1993 | | 1994 | | 1995 | |
| Area | Mean | S. E. | Mean | S. E. | Mean | S. E. | Mean | S. E. |
| Kallipfoni | 2.48 | 0.051 | 2.03 | 0.064 | 2.87 | 0.052 | 2.63 | 0.098 |
| Karditsomagoula | 2.53 | 0.105 | 2.19 | 0.154 | 2.82 | 0.115 | 2.85 | 0.005 |
| Kalivakia | 3.32 | 0.081 | 3.18 | 0.151 | 3.31 | 0.196 | 3.41 | 0.107 |
| Dendrakia | 3.28 | 0.071 | 3.09 | 0.107 | 3.50 | 0.110 | 3.44 | 0.126 |
| Palamas | 2.54 | 0.154 | 1.93 | 0.097 | 2.62 | 0.243 | 2.86 | 0.142 |
| Larissa | 2.86 | 0.071 | 2.85 | 0.135 | 2.73 | 0.119 | 3.00 | 0.117 |
| | One–way analysis of variance | | | | | | | |
| | $F_{value}$ | $P$ | $F_{value}$ | $P$ | $F_{value}$ | $P$ | $F_{value}$ | $P$ |
| | 24.78 | < 0.001 | 23.16 | < 0.001 | 6.83 | < 0.001 | 7.40 | < 0.001 |

productive. Its average yield was 2.69 t/ha against 3.01 t/ha for Acala (Zeta-2 and Zeta-5). Such evidence is in accordance with the results of Galanopoulou and Mitra [5] and the Greek Cotton Organisation [7, 8].

The study of the quantity of the fertilisers used, showed that the fertilisation did not significantly affect production. However the frequent use of high quantities of nitrogen did cause negative hyperfertilisation effects.

The yield was also affected by previous land uses. The one-way analysis of variance showed that there were differences ($P < 0.001$) in the mean values of yield between the five groups formed on the basis of previous land uses. The variable, which expresses previous uses, reveals that the fields that were cultivated during the last two years with cereals had the lowest yields compared to those that were cultivated during the last two to four years with cotton. It seems therefore that one or two years are required for the soil to reach satisfactory yield levels after being previously cultivated with cereals. Similar results were reported by Hulugalle and Entwistle [10]. Mitchell and Entry [17] stated that the “Old Rotation cotton experiment” has demonstrated that long-term crop production is sustainable and soil quality can be maintained or improved using an optimal farming plan which will include a 3-year rotation of cotton, winter legumes, corn, small grains and soybeans.

The variable denoting the application of defoliation was positively correlated to yield for the whole number of sampling sites as well as for each year and every soil order and cultivar separately (r = 0.33 to 0.50). The practice of defoliation is applied to accelerate the opening of the ripe bolls and to limit the late insect attacks and bolls decomposition (harmful insects are also removed, along with the leaves).

### 3.2. n-way analysis of variance

(i) Yield-soil order and local conditions relationship**.** The results of the analysis of variance, with the dependent variable being the yield and the independent variables being soil order and the variable that identify the six areas (local conditions), are shown in Table VI. The main effects of the independent variables and the interaction between soil order and local conditions are statistically significant ($P < 0.001$). The statistical significance of this interaction implies that the differences in yield between the different areas depend on soil order.

The results of multiple classification analysis (Tab. VI) show that Vertisols are the most productive soils with a mean yield 0.39 t/ha above the grand mean (2.89 t/ha). The mean yield of Inceptisols is 0.06 t/ha above the grand mean while the Alfisols give 0.39 t/ha below the grand mean. Part of these differences is due to the confounding effects of the soil properties of the three soil orders and probably to the variations of the climate in the six areas. However, when the influence from local interaction was removed (Adjusted Deviation column of Tab. VI) then differences in yield between

**Table VI.** n-way analysis of variance and multiple classification analysis of soil order and local conditions.

Analysis of variance

| Source of variation | d. f. | $F_{value}$ | *P* |
|---|---|---|---|
| Soil order | 2 | 59.465 | 0.001 |
| Local conditions | 5 | 7.105 | 0.001 |
| Soil order × local conditions | 10 | 3.784 | 0.001 |

Multiple classification analysis

| Variables | Unadjusted deviation | Adjusted deviation |
|---|---|---|
| Soil order | | |
| Alfisols | –0.39 | –0.21 |
| Inceptisols | 0.06 | 0.12 |
| Vertisols | 0.39 | 0.11 |
| Local conditions | | |
| Kallipfoni | –0.33 | –0.24 |
| Karditsomagoula | –0.29 | –0.20 |
| Kalivakia | 0.51 | 0.39 |
| Dendrakia | 0.46 | 0.37 |
| Palamas | –0.28 | –0.23 |
| Larissa | 0.04 | –0.02 |

Grand mean = 2.82 t/ha

Inceptisols and Vertisols soil orders reduced from 0.33 t/ha to 0.01 t/ha. Also the removal of this interaction (soil order × local conditions) diminishes the absolute value of the differences between mean yield per area and the grand mean. This shows that the soil order and the local conditions are related (in the context of the yield production).

The ranking of the six areas according to their productivity remains the same after the removal of the above interaction. The most productive are the areas Kalivakia and Dendrakia, then in descending order follow Larissa, Palamas, Karditsomagoula and Kallifoni. These results agree with those of the one-way analysis of variance. This shows that even if we remove the effect (on the mean production of the six areas) of any possible differences in the distribution of different soil classes between the six areas, these areas still differ with respect to their production levels. Thus, we conclude that the differences between the six locations are the effects of other factors than soil orders, possibly of the different climatic conditions.

(ii) Yield-soil order, cultivar and cultivation year relationship. In Table VII the results of the analysis of variance are presented with the dependent variable being the yield and the independent variables being the soil order, the cultivar and the variable that expresses the year of sampling. The main effects of the three variables are significant ($P < 0.001$). This confirms the result of the one-way analysis of variance, namely that the soil order, the cultivar and the different annual climatic conditions resulted in important differences in the yields.

The significant ($P = 0.019$) two-way interaction cultivar × soil order shows that the difference of yield between the two cultivars in the study varies according to the different soil orders. In Alfisols yields are approximately equal (Acala Zeta-2 and Zeta-5: 2.40 t/ha, 4S: 2.43 t/ha). In Vertisols there are small differences (Acala Zeta-2 and Zeta-5: 3.19 t/ha, 4S: 3.23 t/ha) and in Inceptisols there are significant differences (Acala Zeta-2 and Zeta-5: 3.26 t/ha, 4S: 2.66 t/ha). The two-way interaction year × soil order shows that the effects of year varies with soil order ($F_{value} = 2.978$, $P = 0.019$).

**Table VII.** n-way analysis of variance of soil order, cultivation year and cultivar.

| Analysis of variance | | | |
|---|---|---|---|
| Source of variation | d. f. | $F_{value}$ | $P$ |
| Soil order | 2 | 58.082 | 0.001 |
| Cultivation year | 2 | 33.002 | 0.001 |
| Cultivar | 1 | 11.414 | 0.001 |
| Soil order × cult. year | 4 | 2.978 | 0.019 |
| Soil order × cultivar | 2 | 13.399 | 0.001 |
| Cult. year × cultivar | 2 | 1.821 | 0.163 |
| Soil order × cult. year × cultivar | 4 | 1.497 | 0.203 |

The three-way interactions are not significant ($P = 0.203$).

### 3.3. Regression analysis: yield prediction models

#### *3.3.1. Prediction from soil variables*

Multiple regression analysis of yield data [13, 32] on the values of the soil and management variables was conducted. According to Table VIII 37%–50% of the total yield variance was accounted for by the joint influence of the soil variables. The highest percentage appeared for the second year. From Table VIII it can be seen that among the soil variables, soil order, clay content percentage of the top layer (0–25cm) and drainage affect the yield significantly. Carbonates and clay content of the top layer are closely correlated ($r = 0.75$, $P < 0.001$) and therefore do not appear together in the regression equations. On the contrary, drainage and the clay content of the top layer which are poorly correlated ($r = 0.36$, $P < 0.001$) do appear together in the regression equation of the second year. From all the regression equations that were calculated for each year, as well as for each cultivar and every soil order, the yield increases greatly when clay content rises.

The negative coefficients of Z1 and Z2 variables coding of soil orders (Tab. II) and the observation that the coefficients of Z1 are greater than those of

**Table VIII.** Regression equations for soil and management variables[1].

| Variables | 1993 (n = 124) | 1994 (n = 118) | 1995 (n = 105) | 1993-1995 (n = 349) |
|---|---|---|---|---|
| Soil | Yield = 2.11 – 0.53 Z1 – 0.02 Z2 + 0.32 CAR | Yield = 3.70 – 0.58 Z1 – 0.29 Z2 + 0.001 $TEX1^2$ – 0.048 $DRN^2$ | Yield = 2.96 – 0.51 Z1 – 0.08 Z2 – 0.01 TEX1 | Yield = 3.10 – 0.49 Z1 – 0.01 Z2 + 0.01 TEX1 |
| | $R^2$ = 0.44, F = 31.2, $P < 0.001$ | $R^2$ = 0.50, F = 28.2, $P < 0.001$ | $R^2$ = 0.40, F = 22.1, $P < 0.001$ | $R^2$ = 0.37, F = 63.6, $P < 0.001$ |
| Management | Yield = 1.33 – 0.39 DEF + 0.01 DSH + 0.35 TYH – 0.02 N | Yield = – 1.02 – 0.72 DEF + 4.7 PGE + 0.11 PRU – 0.29 ICA | Yield = – 0.58 + 0.01 DSH –- 0.42 DEF + 0.12 IAE + 0.05 N + 0.33 TYH – 0.24 CUL + 0.09 ICW | Yield = – 0.60 – 0.40 DEF – 0.17 ICA + 0.01 DSH + 0.09 PRU + 0.25 TYH + 1.85 PGE + 0.32 WCS |
| | $R^2$ = 0.41, F = 20.7, $P < 0.001$ | $R^2$ = 0.40, F = 19.1, $P < 0.001$ | $R^2$ = 0.47, F = 12.3, $P < 0.001$ | $R^2$ = 0.36, F = 27.2, $P < 0.001$ |
| Soil and management | Yield = 2.13 + 0.27 CAR – 0.41 DEF – 0.55 Z1 – 0.28 Z2 + 0.05 IAE | Yield = – 1.41 – 0.55 Z1 – 0.21 Z2 – 0.63 DEF – 0.19 ICA – 0.13 CAR + 5.80 PGE + 0.08 PRU | Yield = – 0.79 – 0.43 Z1 + 0.01 Z2 – 0.20 CUL – 0.31 DEF + 0.01 DSH – 0.17 WCE + 0.14 IAE + 0.02 TEX2 + 0.05 N | Yield = 0.32 – 0.47 Z1 –0.16 Z2 – 0.16 ICA – 0.33 DEF + 0.09 PRU + 0.01 DSH + 1.70 PGE + 0.01 TEX2 |
| | $R^2$ = 0.53, F = 26.2, $P < 0.001$ | $R^2$ = 0.49, F = 14.9, $P < 0.001$ | $R^2$ = 0.65, F = 19.4, $P < 0.001$ | $R^2$ = 0.43, F = 32.2, $P < 0.001$ |

[1] See Section 2.2. of the text for a description of the variables.

Z2 in all the regression equations confirm the results of ANOVA that Vertisols are the most productive soils and are followed in diminishing order by Inceptisols and Alfisols.

In a regression equation on the soil variables if we replace Z1 and Z2 by their corresponding values for each soil order (Tab. II), we obtain three equations, each of which is a yield prediction model for the corresponding soil order. For example the equation of the second year gives the following three equations (1–3).

Alfisols:

$$\text{Yield} = 3.12 + 0.001\ \text{TEX1}^2 - 0.048\ \text{DRN}^2 \qquad (1)$$

Inceptisols:

$$\text{Yield} = 3.40 + 0.001\ \text{TEX1}^2 - 0.048\ \text{DRN}^2 \qquad (2)$$

Vertisols:

$$\text{Yield} = 3.70 + 0.001\ \text{TEX1}^2 - 0.048\ \text{DRN}^2. \qquad (3)$$

From the value of the constant term in the above equations (1–3) it appears that Vertisols soils have the higher productivity dynamics.

#### *3.3.2. Prediction from management variables*

In the regression equations with independent variables the management variables (Tab. VIII), the multiple determination coefficients $R^2$ which were calculated for every year, ranged from 0.36 to 0.47. The highest value appeared in the third year.

From Table VIII the following remarks can be made. The variable which denotes the application or not of defoliation is present in all regression equations with negative coefficients, which means, considering its coding, that it positively affects the yield. Also, we can conclude (considering the regression coefficients and the coding of the parameters) that the hand harvesting, the length of growing period, the percentage of germination, the number of irrigations, the previous cultivation of sampling sites for two to four years with cotton and the insect control for worms positively affect the yield. On the contrary, the nitrogen excessive fertilisation which is observed in the area and the number of applications of insecticides for aphids sp. negatively affect the yield. The negative coefficient of cultivar variable in the equation for the second year confirms the result of ANOVA that Acala cultivar (code 0) is more productive than 4S [5].

#### *3.3.3. Prediction from soil and management variables*

When the soil and management variables are examined together, the percentage of yield variance accounted for rises up to 65% for the third year, while for the first and second year it is 53% and 49% respectively (Tab. VIII).

### 3.4. Factor analysis

Factor analysis was used to quantify the association of each independent variable with yield, to rank the independent variables in order of contribution to the variance of yield and also to reduce collinearity among independent variables.

Factor analysis was conducted for all the sampling sites and (i) for the entire set of variables or (ii) for the set of variables without yield. In the first case the relationship between yield and the independent variables is extracted from the results of the factor analysis. In the second case, a new set of uncorrelated variables is determined and a quantitative model of yield prediction can be found by regression analysis. Both uses of factor analysis are widely used by many researchers [16, 19, 30].

In Table IX the results of the first factor analysis are presented. Ten factors were extracted that explain the relationship between yield and the independent variables. The factor weights were squared in order to express the variance of the variable that can be accounted for by the corresponding factor. The variance of the variable accounted for by all the factors (communality) is given by the sums of squares of the respective factor weights. The signs of the factor weights show the positive or the negative correlation between the variables in each factor.

The ordering and grouping of the variables are based on the portion of their variance that is explained by each factor. The factor which explains the greatest portion of the total variance is presented first. The variables that carry the greatest weights in the first factor (bold numbers in column

**Table IX.** Factor weights of the studied variables for each factor.

| Variables | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | Communality |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil order | **0.811** | 0.001 | –0.010 | –0.003 | 0.002 | –0.003 | –0.024 | 0.015 | 0.003 | –0.033 | 0.910 |
| Percent clay 0–25 cm | **0.738** | 0.000 | 0.005 | 0.062 | 0.021 | 0.010 | –0.006 | –0.003 | 0.000 | 0.000 | 0.850 |
| Carbonates | **0.543** | –0.003 | 0.063 | 0.019 | 0.037 | 0.079 | –0.003 | –0.007 | –0.002 | –0.007 | 0.760 |
| Percent clay 25–75 cm | **0.399** | 0.000 | 0.004 | 0.347 | 0.003 | 0.005 | –0.022 | 0.000 | –0.001 | 0.001 | 0.780 |
| Type of harvesting | **0.307** | 0.005 | 0.000 | 0.004 | 0.007 | 0.039 | –0.164 | 0.000 | 0.003 | –0.010 | 0.540 |
| Irrigation after emergence | **–0.120** | –0.034 | 0.003 | –0.040 | 0.000 | 0.002 | 0.000 | 0.002 | 0.010 | –0.006 | 0.220 |
| Cultivation year (1993–1994–1995) | 0.000 | **0.941** | –0.001 | –0.002 | 0.005 | 0.001 | 0.007 | –0.019 | 0.000 | –0.007 | 0.980 |
| Previous use | –0.002 | **0.290** | –0.017 | –0.001 | –0.005 | –0.057 | –0.005 | –0.004 | 0.006 | –0.007 | 0.400 |
| Weed control after emergence | 0.025 | **0.169** | 0.001 | –0.001 | –0.001 | 0.034 | 0.001 | 0.007 | –0.146 | 0.004 | 0.390 |
| Insect control for aphids | –0.023 | **–0.135** | –0.004 | –0.007 | –0.076 | 0.005 | 0.004 | –0.002 | 0.000 | 0.001 | 0.260 |
| Percentage of germination | 0.000 | **0.092** | 0.002 | –0.002 | 0.086 | 0.004 | 0.074 | 0.008 | –0.020 | 0.002 | 0.290 |
| Erosion | 0.000 | –0.002 | **0.839** | 0.001 | 0.001 | 0.000 | 0.001 | –0.003 | 0.000 | 0.000 | 0.850 |
| Slope | 0.004 | –0.001 | **0.625** | –0.002 | 0.002 | 0.020 | 0.004 | –0.009 | 0.000 | –0.013 | 0.680 |
| Percent clay 75–150 | 0.006 | –0.003 | 0.005 | **0.667** | 0.000 | 0.010 | –0.011 | 0.001 | 0.001 | 0.000 | 0.700 |
| Drainage | 0.110 | 0.000 | –0.024 | **0.390** | –0.012 | 0.000 | 0.005 | 0.020 | 0.000 | –0.001 | 0.560 |
| Number of days from sowing to harvest | 0.031 | –0.004 | 0.006 | 0.000 | **0.306** | 0.016 | –0.019 | –0.006 | –0.005 | –0.004 | 0.400 |
| Yield | 0.197 | 0.095 | –0.001 | 0.001 | **0.233** | –0.021 | –0.037 | –0.002 | 0.016 | 0.002 | 0.610 |
| Re–sowing | 0.000 | –0.016 | 0.000 | 0.004 | **–0.096** | –0.002 | 0.007 | 0.000 | –0.003 | 0.046 | 0.180 |
| Local climatic conditions | 0.075 | 0.001 | 0.011 | 0.000 | 0.176 | **0.355** | –0.008 | –0.029 | –0.002 | –0.077 | 0.730 |
| Phosphorus | 0.007 | –0.010 | –0.010 | 0.002 | 0.006 | **0.224** | 0.001 | 0.001 | 0.001 | 0.002 | 0.250 |
| Irrigation before germination | 0.000 | 0.002 | 0.026 | 0.006 | –0.009 | **0.135** | –0.002 | –0.005 | –0.001 | 0.001 | 0.190 |
| Spacing-out | –0.019 | –0.018 | –0.001 | –0.015 | 0.051 | **0.079** | 0.002 | 0.018 | –0.002 | 0.014 | 0.220 |
| Cultivar | –0.012 | –0.005 | 0.004 | –0.003 | –0.005 | 0.000 | **0.362** | 0.002 | 0.000 | 0.012 | 0.410 |
| Defoliation | 0.087 | –0.017 | –0.002 | 0.000 | 0.066 | 0.000 | **–0.327** | 0.000 | 0.000 | 0.017 | 0.520 |
| Quantity of seed | 0.000 | 0.000 | –0.009 | 0.008 | –0.002 | 0.000 | 0.017 | **0.712** | 0.004 | 0.008 | 0.760 |
| Insect control for worms | 0.003 | 0.000 | 0.081 | –0.004 | 0.002 | 0.080 | 0.028 | **–0.131** | 0.000 | 0.023 | 0.350 |
| Weed control before sowing | 0.002 | 0.000 | 0.000 | 0.000 | –0.001 | 0.001 | 0.000 | 0.005 | **0.525** | 0.003 | 0.540 |
| Nitrogen | –0.008 | –0.003 | –0.003 | 0.000 | –0.009 | 0.006 | 0.001 | 0.001 | 0.002 | **0.387** | 0.420 |
| Percentage of total variance accounted for by each factor (eigenvalue) | **32.3** | **15.2** | **13.7** | **9.6** | **6.8** | **5.8** | **5.1** | **4.4** | **3.8** | **3.2** | |

F1) form the first group and they are presented according to diminishing weights. The variables that carry the greatest weights in the second factor (F2) form the second group and this process is carried out up to the last factor. The last row of the table shows that the first factor explains 32.3% of the variance for all the variables (eigenvalue F1 = 32.3%), the second explains 15.2% and finally the four first factors together explain 70.8%. The percentage of the variance of each variable that is explained by all the factors (communalities) ranges from 18% to 91% (last column of Tab. IX). More specifically, the yield communality that is explained by the ten factors is 61%. An examination of the yield weights for the ten factors shows that there are three fundamental factors that determine yield, namely factors F1, F2 and F5. An examination of the variables that have the highest weights on these factors shows that soil order, texture of surface and subsurface layer, carbonates, type of harvesting and number of irrigations after emergence identify factor F1. Cultivation year, previous land uses, weed control after emergence, number of applications of insecticides and percentage of germination identify factor F2. Factor F5 is identified by the variables expressing the number of days between sowing and harvesting and the application or not of re-sowing. Factor F7 (cultivar and defoliation) also affects yield by a smaller percent than the three previous factors.

Having found the relationships between the examined variables and having identified the groups of variables that mainly influence the yield the next step was to test whether we could find a model for the prediction of yield from the groups of variables resulting from a factor analysis. This was achieved by applying factor analysis without including yield among the variables and identifying a smaller set of variables (factors) that accounted for most of the variance of the initial variables and using the values of each factor for each sampling site (factor score) in a regression equation with yield as the independent variable.

Ten factors were also extracted. Each extracted factor was identified by the same group of variables as those presented in Table IX. A forward stepwise regression analysis with the yield as the dependent variable and the factor scores as the independent variables resulted in equation (4).

$$\text{Yield} = 281.612 + 30.117\ \text{Fsc1} + 20.376\ \text{Fsc2} - 19.196\ \text{Fsc5} - 11.403\ \text{Fsc7} \quad (4)$$

$$R^2 = 0.41,\ F = 57.871,\ P < 0.001$$

where: Fsc1, Fsc2, Fsc5, Fsc7 are the variables expressing the factor scores of F1, F2, F5 and F7 factors respectively.

The factor analysis model presented in Table IX gives the structure of the dependence and the interrelationships between cotton yield (dependent variable) and soil, climate and management variables (independent variables). The factor analysis without yield, followed by a regression analysis with the yield as the dependent variable, shows the same structure of dependence between the yield and the independent variables but it has the advantage that the relationships between dependent and independent variables are quantified in the form of a production function.

## 4. Conclusions

In this paper the influence of soil, climate and management variables on the cotton yield from six areas of Thessaly plain was studied for three consecutive growing seasons. The combined use of statistical methods such as one-way and n-way analysis of variance, regression analysis and factor analysis confirmed the role of these variables on cotton yield.

The results from ANOVA can be summarised as follows: (a) soil order, texture and carbonates especially of the top layer are very important soil variables for cotton production. The three soil orders studied were characterized by different productivity levels. Vertisols were the most productive (3.20 t/ha) while Alfisols were less productive (2.43 t/ha). (b) The management variables, cultivar, previous use of the sampling sites and defoliation also affected the yield. From the two cultivars used Acala (Zeta-2 and Zeta-5) was the most productive. (c) The different climatic conditions which were expressed either from the temporal variation of the climate between the three growing seasons (cultivation year variable) or from its spatial variation between the six areas (local conditions variable) caused different average yields between the three years and the six areas. (d) The interactions cultivation year × soil order, local conditions × soil order and soil order × cultivar affected the yield significantly.

The multiple regression analysis suggested that the soil variables accounted for almost 50% of the total yield variance. About the same percentage of yield variance was accounted for by the management variables. When soil and management variables were entered into the regression equation the coefficient of multiple determination ($R^2$) reached the value of 0.65.

Factor analysis provided insight into relations between variables and allowed the grouping of these variables into ten combinational ones (factors). Factor analysis was applied in two ways, including, or not, yield in the set of initial variables. Both factor analysis applications confirmed the results of ANOVA and regression analysis. The variables from ANOVA and regression found to affect yield were grouped into four factors, F1, F2, F5 and F7, and a production model based on the factor scores was developed.

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