

Assessing Production Efficiency of Dairy Farms in Burdur Province, Turkey	1	T. Binici, V. Demircan, C. R. Zulauf
A Profitability Analysis of Investment of Peach and Apple Growing in Turkey	11	M. Uzunöz, Y. Akçay
Economic Assessment of Hazelnut Production and the Importance of Supply Management Approaches in Turkey	19	S. Göneç, H. Tanrıvermiş, M. Bülbül
Crop Coefficient of Haricot Bean at Melkassa, Central Rift Valley of Ethiopia	33	S. Laike, K. Tilahun, T. Hordofa
Influence of Cereal-Legume Rotation on <i>Striga</i> Control and Maize Grain Yield in Farmers' Fields in the Northern Guinea Savanna of Nigeria	41	I. Kureh, A. Y. Kamara, B. D. Tarfa
Effects of a Polymer for Soil Amendment on Yield Formation of Millet under Arid Conditions	55	S. Banedjschafie, H. Herzog
Variation in the Response of Seed and Embryonic Axes to Incubation Temperature Gradients during Seed Treatments in Pearl Millet and Sorghum	67	M. A. Kader
Estimation of Erosion Danger Lands of the Reclamation Fund in Georgia	85	G. P. Gogichaishvili, T. T. Urushadze
Book Reviews	95	
News in Brief	99	

## **Journal of Agriculture and Rural Development in the Tropics and Subtropics**

formerly:

Der Tropenlandwirt. Beiträge zur tropischen Landwirtschaft und Veterinärmedizin,  
Journal of Agriculture in the Tropics and Subtropics

ISSN 1612-9830

### **Publisher**

German Institute f. Tropical and Subtropical Agriculture (DITSL GmbH), Witzenhausen  
Association for Sustainable Development (GNE mbH), Witzenhausen  
Institute for tropical Agriculture e.V., Leipzig  
University of Kassel, Faculty of Organic Agricultural Sciences, Witzenhausen  
Association of Agronomists in the Tropics and Subtropics Witzenhausen, e.V. (VTW)

### **Executive Manager and Editor in Chief**

Hans Hemann, Steinstraße 19, D 37213 Witzenhausen, Fon: ++49 (0)5542 - 981216,  
Fax: ++49 (0)5542 - 981313, Email: tropen@wiz.uni-kassel.de

### **Editors**

Prof. Dr. E. Baum	Dr. E. Klinge von Schultz	Dr. S. Tesfai
Prof. Dr. J. Borgman	Prof. Dr.-Ing. R. Krause	Prof. Dr. P. Wolff
Dr. habil. h.c. W. Drauschke	Dr. H. Lehmann - Danzinger	
Dr. J. Gebauer	Prof. Dr. J. Pohlan	
Prof. Dr. habil. K. Hammer	Prof. Dr. Ch. Richter	
Dr. Ch. Hülsebusch	Prof. Dr. E. Tawfik	

### **Subscription**

The *Journal of Agriculture and Rural Development in the Tropics and Subtropics* is published twice a year (April and October). It may be subscribed by a price of € 30,- + shipping. The subscription is for at least one year and is automatically extended unless otherwise stated by the subscriber till the end of the year. Single copies may be purchased for € 20,- + shipping.

Orders may be placed at Kassel University Press, Diagonale 10, D-34127 Kassel (www.upress.uni-kassel.de), Fon ++49 (0)561 804 2159, Fax ++49 (0)561 804 3429 or at any bookstore.

### **Publishing House**

kassel university press GmbH  
www.upress.uni-kassel.de

### **Composition and Layout**

BIERWIRTH & GABELE SOFTWAREDESIGN GbR, Steinstr. 19, Postfach 1128,  
D - 37201 Witzenhausen, <http://www.bg-softwaredesign.de>

Cover layout: Jochen Roth, Melchior v. Wallenberg, Kassel

Printed by: Uniprinter University of Kassel

## Assessing Production Efficiency of Dairy Farms in Burdur Province, Turkey

T. Binici<sup>\*1</sup>, V. Demircan<sup>2</sup> and C. R. Zulauf<sup>3</sup>

### Abstract

This study finds that a sample of 132 dairy farmers located in Burdur Province, Turkey, are producing at a low level of production efficiency. Efficiency ranges from 24 percent to 94 percent, with the average being 50 percent. Eighty one percent of the variation in output among the sampled farmers is due to differences in their production efficiency. If a farmer with average efficiency improved efficiency to that of the most efficient farmer in the sample, then the average dairy farmer could realize a 47 percent saving in cost. Two statistically significant factors associated with the variation in production efficiency are identified: the type of feeding system used and herd size. Use of extension programs explained little of the variation in production efficiency.

**Keywords:** stochastic frontier analysis, production efficiency, dairy farms

### 1 Introduction

Turkey's dairy sector historically has been one of its most important farm sectors both in terms of value added and employment. However, since 1990, milk production in Turkey has decreased from 9.6 million tons per year to 8.2 million tons/year, a decline of 15.3 percent (FAO, 2003). Over the same period, number of dairy cows has decreased from 5.9 million in 1990 to 4.2 million in 2003, or by 29 percent.

To help its dairy sector cope with its decline, Turkey has adopted various public policies. They include a milk premium, a livestock headage payment and roughage feed support program. Because Turkey is seeking admission to the European Union, these policies have come under review as Turkey aligns its agricultural policy with EU agricultural policy. In addition, World Trade Organization rules require countries to reduce their trade barriers, including their custom level. These policy changes are likely to exacerbate the economic pressures that have developed in Turkey's dairy industry over the last quarter century.

---

\* corresponding author

<sup>1</sup> Turan Binici, Assistant professor at the Department of Agricultural Economics, Harran University, Sanliurfa, Turkey. E-mail: turanbinici@yahoo.com

<sup>2</sup> Vecdi Demircan, Assistant professor at the Department of Agricultural Economics, Suleyman Demirel University, Turkey.

<sup>3</sup> Carl R. Zulauf, Professor at Ohio State University, Department of Agricultural, Environmental, and Development Economics, Ohio, USA

A key to improving the competitiveness of Turkey's dairy industry is to improve its economic efficiency. Numerous studies have examined dairy production efficiency in both developed and developing countries. Recent studies include MBAGA *et al.* (2003) and SHARMA and GULATI (2003). However, to the authors' knowledge, no study has examined the production efficiency of dairy farms in Turkey. The objective of this study is to analyze the production efficiency of dairy farms in Burdur Province, Turkey and to determine farm specific factors that are associated with the variation in efficiency among dairy farmers.

## 2 Material

The data used in this study were collected through personal interviews with dairy farmers in Burdur Province, Turkey, during the Spring of 2004. This area was selected because milk production and processing are important activities. Forty six percent of farm income comes from the dairy sector in Burdur Province, which is much higher than the 32 percent average for Turkey (SIS, 2003).

A two stage sampling process was used. In the first stage, 18 villages in Burdur, Bucak and Yesilova Counties were identified through communication with the Directory of Agriculture in Burdur Province. According to farms records of the Directory of Agriculture, 80 percent of the dairy cows in Burdur Province are located in these counties. The farmers in the 18 villages formed the population for this study.

In the second stage, 138 farmers from the 18 villages were chosen for interviews using a stratified random sampling procedure. The sample was stratified by herd size. Useable interviews were obtained for 132 farms, which form the data set for this study. The sampling parameters are presented in Table 1.

**Table 1:** Sampling Parameters of Dairy Producers, Burdur, Bucak and Yesilova Counties, Burdur Province, Turkey, 2004.

<i>Herd Size (cows)</i>	<i>Farmer population</i>	<i>Farmers sampled*</i>	<i>Distribution of sampled farmers</i>
1-5	1022	54	41 %
6-10	640	43	33 %
11+	554	35	26 %
Total	2216	132	100 %

\* These are farmers with useable interviews. The original sample included 138 dairy farmers.

A wide range of socio-economic and business characteristics were elicited in the interview. They included number of cows, amount of milk produced, major dairy inputs (feed, labor, capital, and cultivated land), hectares of fodder crops, operator's education and age, farm contact with extension, and membership in cooperative and producer organizations.

Descriptive statistics of the variables are presented in Table 2. The dairy herds ranged from 1 to 48 cows. The average was 10 cows. Input use varied substantially, with the maximum use being at least 11 times the minimum use for each of the four major input categories.

**Table 2:** Characteristics of Surveyed Dairy Producers, Burdur, Bucak and Yesilova Counties, Burdur Province, Turkey, 2004.

<i>Variable</i>	<i>Mean</i>	<i>Standard deviation</i>	<i>Minimum</i>	<i>Maximum</i>
Herd Size (number)	10	9	1	48
Annual Milk Production (kg/cow)	2111	899	340	6750
Concentrate Feed (kg/herd)	1570	574	225	4500
Roughage Feed * (kg/herd)	1796	1130	2	6525
Human Labor (Man-days/herd )	30	17	6	91
Farm Capital (New Turkish Lira/herd)	4019	2414	1610	18100
Fodder Crop (ha)	2.6	2.4	0	14.1
Education Attainment (years)	6	2	0	15
Age (years)	48.5	13.5	23	75
Use Individual Feeding System (%)	62			
Contact with Extension (%)	66			
Cooperative Member (%)	100			

\* Roughage feed equals the consumption of succulent roughage plus dry roughage, assuming a dry matter content of 30 % and 90 % respectively.

### 3 Methods

FARRELL (1957) developed the first theoretical treatment of production technical efficiency (hereafter, referred to as production efficiency). The standard methodology for measuring farm level production efficiency is to estimate a production frontier that envelopes all the input/output data available for the analysis. Within this context, technical efficiency of a farm is measured relative to the input/output performance of all other farms in the sample. Farms located on the production frontier are considered efficient. Farms located inside the frontier are considered inefficient because the farm is generating less output that is feasible given its level of inputs.

A Cobb-Douglas production function is used to estimate the stochastic production frontier (SPF)<sup>4</sup>. This function has been widely used to analyze production efficiency in developing and developed countries (BRAVO-URETA and RIEGER, 1991; SHARMA *et al.*,

<sup>4</sup> In preliminary analyses, the Cobb-Douglas model was found to adequately represent the data, given the specification of a translog stochastic frontier involving the four input variables.

1999; BINAM *et al.*, 2004). TAYLOR *et al.* (1986) argued that, despite its well-known limitations, the Cobb-Douglas function provides an adequate representation of production technology as long as the analysis is interested in the efficiency of production and not the structure of the production technology.

Given the choice of the Cobb-Douglas production function, the data available from the survey, and the objective of explaining the variation in production efficiency among the sampled dairy farms, the following SPF model was estimated<sup>5</sup>:

$$\ln Y_i = \beta_0 + \sum_{j=1}^4 \beta_j \ln X_{ji} + v_i - u_i \quad (1)$$

and

$$u_i = \delta_0 + \sum_{m=1}^6 \delta_m Z_{mi} \quad (2)$$

where,  $\ln$  denotes natural logarithm;  $Y_i$  is annual milk production of farm  $i$  measured in kilograms;  $X_{1i}$  is annual consumption of purchased dairy concentrate in tons;  $X_{2i}$  is annual consumption of roughage feed in tons (equals consumption of succulent roughage plus dry roughage, assuming a dry matter content of 30 % and 90 % respectively (BRAVO-URETA and RIEGER, 1991);  $X_{3i}$  is human labor in man-days;  $X_{4i}$  is total farm capital defined by opportunity cost of total value of assets in New Turkish Lira (TL), and  $Z_{mi}$  are socio-economic characteristics.  $v_i$  is a symmetric, identically and independently distributed  $N(0, \sigma_v^2)$  error term. It represents random variation in production due to random exogenous factors, such as measurement errors, unobserved production inputs, and statistical noise.  $u_i$  is a non-negative error term. It reflects technical inefficiency relative to the stochastic frontier.

The socio-economic characteristics ( $Z_{mi}$ ) examined in this study were defined as follows.  $Z_{1i}$  is farmer age.  $Z_{2i}$  is a binary variable equal to one if the farmer had a degree higher than elementary school and to zero otherwise.  $Z_{3i}$  is a binary variable equal to one if the farmer used an individual feeding system and to zero otherwise.  $Z_{4i}$  is a binary variable equal to one if the farmer contacted an extension officer in the past year and to zero otherwise.  $Z_{5i}$  is total number of cows in the herd.  $Z_{6i}$  is number of hectares planted to fodder crops. Because all of the sampled farmers were members of the Agricultural Sale Cooperatives, this variable was not included in the regression equation.

Following COELLI and PERELMAN (1996), technical efficiency of farm  $i$  equal:

$$EEF_i = E [\exp(-u_i) | \varepsilon_i] = E \left[ \exp \left( -\delta_0 - \sum_{m=1}^5 \delta_m Z_{mi} \right) | \varepsilon_i \right] \quad (3)$$

where  $E$  is the expectation operator. The technical inefficiency of farm  $i$ , i.e.  $u_i$ , is conditional upon the observed value of  $\varepsilon$  from the estimated Cobb-Douglas stochastic production frontier.

---

<sup>5</sup> For more detail on the SPF model, see BATTESE and COELLI (1995) and RAHMAN (2003)

Maximum likelihood is used to estimate simultaneously the unknown parameters of the Cobb-Douglas stochastic frontier (Equation 1) and the measure of inefficiency (Equation 2). The likelihood function is expressed in terms of the variance parameters,  $\sigma^2 = \sigma_v^2 + \sigma_u^2$  and  $\gamma = \frac{\sigma_u^2}{\sigma^2}$  (BATTESE and COELLI, 1995).  $\gamma$  must lie between zero and one. Zero indicates that the deviation from production efficiency is due entirely to noise; one indicates that the deviation is due entirely to the farmer's production inefficiency (BATTESE and COELLI, 1995). FRONTIER 4.1 (COELLI, 1996) is used to obtain the maximum likelihood estimates (MLE).

#### 4 Results and Discussion

The estimated Cobb-Douglas production function is presented in Table 3. As expected, the production inputs have a positive coefficient, implying that the amount of milk produced increases as the use of these inputs increase. Except for forage feeds, the coefficients are significant at least at the 95 percent level of statistical confidence.

**Table 3:** Maximum-likelihood estimates of profit frontier function of dairy farmers, Burdur, Bucak and Yeşilova Counties, Burdur Province, Turkey, 2004.

<i>Variable</i>	<i>Parameters</i>	<i>Coefficients</i>	<i>t-ratio</i>
Constant	$\beta_0$	2.03	1.00
$\ln(\text{concentrate feed})$	$\beta_1$	0.284*	4.11
$\ln(\text{forage feed})$	$\beta_2$	0.06	1.54
$\ln(\text{labor})$	$\beta_2$	0.15*	2.64
$\ln(\text{capital})$	$\beta_3$	0.39**	2.54
<i>Variance parameters</i>			
$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.12	5.82
$\gamma = \frac{\sigma_u^2}{\sigma^2}$		0.89*	6.08
Log likelihood		-0.37	
LR statistic		14.56	

\*, \*\* significant at the 1 and 10% level respectively

To test for efficiency, the following base calculations were made:  $\sigma^2 = \sigma_v^2 + \sigma_u^2 = 0.115$  and  $\gamma = \frac{\sigma_u^2}{\sigma^2} = 0.89$ . The null hypothesis that  $\gamma = 0$  is rejected at the 99% level of statistical confidence (LR test statistics is 14.56), indicating that technical inefficiency

effect exists. A  $\gamma^*$  of 0.81 indicates that 81 percent of the variation in output among the dairy farmers is due to differences in production efficiency<sup>6</sup>.

Table 4 presents the distribution of production efficiency scores. Only two percent of the 132 sampled dairy farms had a production efficiency score that meant the farm was operating at 90 percent or more of their potential production efficiency based on the estimated production efficiency frontier. The highest score was 94 percent. The lowest score was 24 percent, and the average score was 50 percent. Fifty-nine percent of the sampled dairy farms were operating at less than 50 percent efficiency. When taken as a group, these scores suggest considerable potential for improving production efficiency by increasing output and/or reducing inputs. For example, if a farmer with average efficiency increased the farm's efficiency to that of the most efficient farm in the sample, this average dairy farmer could realize a 47 percent (i.e.,  $1 - (50/94)$ ) saving in costs.

**Table 4:** Distribution and summary statistics for production efficiency scores of dairy farmers in Burdur, Bucak and Yesilova Counties, Burdur Province, Turkey, 2004.

<i>Production Efficiency Score (%)</i>	<i>Number of Dairy Farms</i>	<i>Percent of Dairy Farms</i>
>90.0	2	2
>80.0 ≤90	8	6
>70.0 ≤80	7	5
>60.0 ≤70	15	11
>50.0 ≤60	23	17
>40.0 ≤50	35	27
>30.0 ≤40	28	21
>20.0 ≤30	14	11
Less Than 20	0	0
Mean	50	
Minimum	24	
Maximum	94	

Previous studies of the production efficiency of dairy farms have found that on average production efficiency was 83 percent for a sample of U.S. (New England) dairy farms (BRAVO-URETA and RIEGER, 1991), 92 percent to 95 percent depending on type of production function specified for a sample of Canadian (Quebec) dairy farmers (MBAGA *et al.*, 2003), 77 percent for a sample of Ecuadorian dairy farms (BAILEY *et al.*, 1989), 79 percent and 84 percent for a sample of dairy farmers in the Northern and Western

<sup>6</sup>  $\gamma$  does not equal the ratio of the variance of inefficiency to total residual variance. The reason is that the variance of  $u_i$  equals  $\left(\frac{\pi-2}{\pi}\right)\sigma^2$ , not  $\sigma^2$ . Thus, the relative contribution of inefficiency to total variance  $\gamma^*$  equals  $\frac{\gamma}{\left(\frac{\gamma+(1-\gamma)\pi}{\pi-2}\right)}$  (RAHMAN, 2003).



regions of India, respectively (SHARMA and GULATI, 2003). This comparison does not mean that this sample of Turkish dairy producers is less efficient than these dairy farmers in other countries. The reason is that the production frontier may differ among each country. This comparison only means that, relative to their production frontier, the sample of Turkish dairy farmers Burdur province did not operate as close to their production frontier as did the producers in the other studies.

Table 5 contains the results for the regression analysis of the factors associated with the variation in production efficiency among the sampled farms. The dependent variable is the degree of production efficiency (see equation 3). Because of the way that equation 3 is written, a variable with negative sign means that it is positively related to the efficiency of the farm.

**Table 5:** Maximum-likelihood estimates of variables associated with production efficiency of dairy farmers, Burdur, Bucak and Yeşilova Counties, Burdur Province, Turkey, 2004.

<i>Variable</i>	<i>Parameter</i>	<i>Coefficient</i>	<i>t-ratio</i>
Constant	$\delta_0$	0.893	2.40
Age	$\delta_1$	-0.032	-0.85
Education	$\delta_2$	-0.043	-0.59
Feeding Type	$\delta_3$	-0.164*	-2.12
Contact with Extension	$\delta_4$	-0.050	-0.68
Total Herd Size	$\delta_5$	-0.067*	-1.80
Forage Feed land	$\delta_6$	0.002	1.10

\* significant at the 5 % level

This study finds that age is positively related with production efficiency but is statistically insignificant at the 90 percent level of statistical confidence. This finding is in line with the expected *a priori* indeterminate relationship. Older farmers have acquired more human capital through their experiences, but they also may be less willing to adopt new ideas. Consistent with this *a priori* expectation, findings from empirical previous studies are mixed. For example, ABDULAI and HUFFMAN (1998) find that older rice farmers in Northern Ghana were less efficient than younger farmers while COELLI *et al.* (2002) find that younger rice farmers in Bangladesh were more efficient than older rice farmers. BINICI *et al.* (2006) found that age has no statistically significant effect on the technical efficiency of cotton farms in Turkey.

Education is positively associated with efficiency, but it is statistically insignificant. Similar results were reported for farmers in Bangladesh (RAHMAN, 2003), Ethiopia (WEIER, 1999), and Cameroon (BINAM *et al.*, 2004). Conceptually, education improves the skill

and entrepreneurial ability of the farmer to organize inputs for maximum efficiency. However, JOSHI (1998) argues that the gains from education are higher in modernized agriculture than in traditional agriculture. The findings in this study are consistent with Joshi's argument.

Contact with an extension officer during the past year was positively related to efficiency but statistically insignificant. This finding is consistent with the findings of FEEDER *et al.* (2004); BINAM *et al.* (2004); RAHMAN (2003). Each of these studies involved farmers in developing countries. The inability to find statistical significance has been attributed to bureaucratic inefficiency, poor program design, (FEEDER *et al.*, 2004; BINAM *et al.*, 2004) and the use of a "top-down" instead of participatory approach (BRAUN *et al.*, 2002). Turkey's extension program has been characterized by a top-down approach (AKTAŞ, 2004). Thus, the lack of a participatory approach may explain the insignificance of Turkey's extension program in terms of its impact on the efficiency of these Turkish dairy farms.

The number of hectares of fodder crops is statistically insignificant and does not have the expected sign. Farmers who harvest larger acreages of fodder crops may use too much roughage in their feed rations because it is available. Proper nutritional balance between feed concentrates and roughage feed is widely recognized as a key to attaining production efficiency (BAILEY *et al.*, 1989).

In the study area, two types of feeding systems are used. In one system, the cows are fed individually. In the other system, the cows are fed as a group. Use of an individual feeding system was associated with a greater degree of efficiency. This relationship was significant at the 95 percent level of statistical confidence. One reason that an individual feeding system is more efficient is that the farmer can feed each cow a ration tailored to her production potential. In a group feeding system, the highest producing cows may not produce to their potential because they may not necessarily eat the right amount of feed.

Farm size had a positive relationship with dairy farm efficiency. This relationship was significant at the 95 percent level of statistical confidence. It is consistent with previous studies (BRAVO-URETA and RIEGER, 1991; TAUER, 2001) and with the expected existence of economies of size from economic theory.

## **5 Conclusion and Policy Implications**

Stochastic Production Frontier analysis is used to analyze the production efficiency of a sample of 132 dairy farmers located in Burdur Province, Turkey. These farms have an average efficiency score of 50 percent. Further analysis reveals that 81 percent of the variation in output among the sampled farmers is due to differences in their production efficiency. These findings imply that the average dairy farmer in this sample has the potential to substantially increase their efficiency without changing their production frontier. Operating at a high efficiency relative to the production frontier is an important factor in remaining competitive and thus in business over time.

The analysis identified two statistically significant factors associated with the variation in production efficiency: individual instead of group feeding of cows, and larger herd size. Both factors are potentially attainable, although both have implementation costs. In particular, policy makers either must allow market forces to reward the formation of larger dairy farms or they must implement policies that help small dairy producers adjust by either getting larger, or by developing niche markets, or by exiting dairy farming, including the potential use of public funds to pay an exit bonus.

Individual feeding of cows could become the centerpiece of a national education campaign to improve dairy herd production efficiency. However, this study finds no statistically significant relationship between contact with extension and the degree of farm production efficiency. Thus, the success of a national education campaign to raise awareness of the value of individual dairy feeding systems may require a revamping of Turkey's extension program. If this option is deemed infeasible by policy makers, an alternative approach may be to create a separate program using other delivery mechanisms.

### **Acknowledgement**

We are grateful to Suleyman Demirel University that has funded this research, No: 0906-M-04.

### **References**

- ABDULAI, A. and HUFFMAN, W. E.; An examination of profit inefficiency of rice farmers in Northern Ghana; Staff paper, Swiss Federal Institute of Technology, Department of Agricultural Economics; 1998.
- AKTAŞ, Y.; Evaluating of the model for integrated pest management in cotton by contact farmers in the Harran Plain; *Journal of Agriculture and Rural Development in the Tropics and Subtropics*; 105(2):105–122; 2004.
- BAILEY, D. V., BISWAS, B. and KUMBHAKAR, S. C.; An Analysis of Technical, Allocative, and Scale Inefficiency; *Western Journal of Agricultural Economics*; 14:30–37; 1989.
- BATTESE, G. E. and COELLI, T. J.; A model for technical inefficiency effects in a stochastic frontier production function for panel data; *Empirical Economics*; 20:325–332; 1995.
- BINAM, J. N., TONYE, N. W., NYAMBI, G. and AKOA, M.; Factors affecting the technical efficiency among smallholder farmers in the slash and burn agriculture zone of Cameroon; *Food Policy*; 29:531–545; 2004.
- BINICI, T., KAÇIRA, Ö., ZULAUF, C. R. and KARLI, B.; Assessing the efficiency of cotton production in the Harran plain, Turkey; *Outlook on Agriculture*; 35(3); 2006; (in press).
- BRAUN, A., THIELE, G. and FERNANDEZ, M.; Farmer field schools and local agricultural research committee: complementary platforms for integrated decision-making in sustainable agriculture; ODI, Agricultural Research and Extension, Network Paper 105; 2002.
- BRAVO-URETA, B. E. and RIEGER, L.; Dairy farm efficiency measurement using stochastic frontiers and neoclassical duality; *American Journal of Agricultural Eco-*

- nomics*; 73:421–428; 1991.
- COELLI, T., RAHMAN, S. and THIRTLE, C.; Technical, allocative, cost and scale efficiencies in Bangladesh rice cultivation: A non-parametric approach; *Journal of Agricultural Economics*; 53:607–626; 2002.
- COELLI, T. J.; A Guide to Frontier Version 4.1: A computer program for frontier production function estimation; CEPA Working Paper 1996/07, Department of Econometrics, University of New England, Armidale; 1996.
- COELLI, T. J. and PERELMAN, S.; Efficiency measurement, multi-output technologies and distance functions: with application to European railways; CREEP WP 96/05, Centre de Recherche en Economie de la Population, Universite de Liege; 1996.
- FAO; Production yearbook of Turkey; FAO, Rome; 2003.
- FARRELL, M. J.; The measurement of productive efficiency; *Journal of Royal Statistics of Society*; 120:253–281; 1957.
- FEEDER, G., MURGAI, R. and QUIZION, J. B.; Sending farmers back to school: the impact of farmer field schools in Indonesia; *Review of Agricultural Economics*; 26:45–62; 2004.
- JOSHI, P. K.; Education, technology adoption and agricultural productivity; *Journal of Agricultural Economics*; 56:33–37; 1998.
- MBAGA, D. M., ROMAIN, R., LARUE, B. and LEBEL, L.; Assessing technical efficiency of Quebec dairy farms; *Canadian Journal of Agricultural Economics*; 51:121–137; 2003.
- RAHMAN, S.; Profit efficiency among Bangladeshi rice farmers; *Food Policy*; 28:487–503; 2003.
- SHARMA, K. R., LEUNG, P. and ZALESKI, H. M.; Technical, allocative and economic efficiencies in swine production in Hawaii: a comparison of parametric and nonparametric approaches; *Agricultural Economics*; 20:23–35; 1999.
- SHARMA, V. P. and GULATI, A.; Trade liberalization, market reforms and competitiveness of Indian dairy sector; Discussion paper. International Food Policy Research Institute; 2003.
- SIS; Agricultural structure and production; State Institute of Statistics, Turkey; 2003.
- TAUER, L.; Efficiency and competitiveness of the small New York dairy farm; *Journal of Dairy Science*; 84:2573–2576; 2001.
- TAYLOR, T. G., DRUMMOND, H. E. and GOMES, A. T.; Agricultural credit programs and production efficiency: An analysis of traditional farming in Southeastern Minas Gerais, Brazil; *American Journal of Agricultural Economics*; 68:110–119; 1986.
- WEIER, S.; The effects on education on farmer productivity in Rural Ethiopia; Working paper CSAE WPS99-7. Center for the study African Economics, University of Oxford; 1999.

## A Profitability Analysis of Investment of Peach and Apple Growing in Turkey

M. Uzunöz\*<sup>1</sup> and Y. Akçay<sup>2</sup>

### Abstract

This study was conducted to determine profitability and feasibility of fruit farms by investment analysis in Tokat - Turkey. The criteria of Net Present Value (*NPV*), Cost-Benefit Ratio (*CBR*) and Internal Rate of Return (*IRR*) were used for investment analysis. Three different discount rates (10%, 8% and 5%) were used to get the *NPV* and *CBR* for peach and apple. The *NPV* for peach were found to be positive (1113.6 \$/da; 1454.7 \$/da; and 2156.2 \$/da). Also the *NPV* for apple were found to be positive (574.2 \$/da; 805.4 \$/da; and 1342.9 \$/da). In addition to that, the *CBR* for peach were bigger than 1 (1.38; 1.43 and 1.51) and the *CBR* for apple were bigger than 1 (1.23; 1.27 and 1.33). The *IRR* for peach was 25.05 percent and 22.12 for apple. According to the results that were achieved by the study, it could be conducted that the investment is economically feasible. In the light of the findings of the present study, it can be perceived that the fruit farming can be one of the most important income sources for the farmers growing fruit in the research region in Turkey.

**Keywords:** fruit, internal rate of return, investment analysis, net present value, sensitivity analysis

### 1 Introduction

Turkey lies in the 36-42° north latitude and 26-45° east longitude and possesses a wide range of climatic conditions from mild Mediterranean to cold continental that enable the cultivation of more than 75 crop species. Peach and apple can be grown in various regions of Turkey (HAKAN, 2003; SPO, 2001; ENGINDENİZ *et al.*, 2004). They are widely grown in Tokat province in Middle Blacksea Region and cover 28,1 percent of total planted fruit area.

An orchard is a long-term including establishment and maturity period investment and careful planning is essential to ensure economic success (MARINI, 1997). The producer would like to know the results of his economic activity by working out a detailed cost-benefit analysis of the investment in the project. Although the technical aspects of fruit production have been studied extensively, quantitative studies related to the economics

---

\* corresponding author

<sup>1</sup> Meral Uzunöz, Department of Agricultural Economics, Faculty of Agriculture, University of Gaziosmanpaşa, Taşlıçiftlik 60240, Tokat - Turkey

<sup>2</sup> Yaşar Akçay, see <sup>1</sup>

of such farms are limited in literature. Therefore there is still a need for further study; especially at the local level. The main objective of the study is to analyze the feasibility and profitability of investment in fruit farms.

## 2 Materials and Methods

In the study, the data were obtained from the annual cost table prepared by the Research Institute of Rural Services in the region for the year of 2003. The economic life of the activity is taken as 20 years for peach and 30 years for apple. Establishment period for peach and apple are 5 and 7 years respectively. The profit was calculated and compared with real interest rate to find opportunity costs of enterprise.

Investment in an orchard will generate income and expenses for many years into the future. Discounting these future streams of money is the recommended analytical technique that determines the Net Present Value (*NPV*) in today's money. By comparing the *NPV* of each investment, the most profitable investment over time can be determined by selecting that investment with the highest *NPV* (KELSEY and SCHWALLIER, 1999). In other words the *NPV* is the total present value of future revenues and costs of an activity (CASTLE *et al.*, 1987) and among the measures of investment returns over time, *NPV* offers the better measure of project worth (SWINTON *et al.*, 1997). The consensus in the investment literature is that if the objective of a firm is the maximization of profit or wealth of a business, then the *NPV* model is the appropriate procedure to evaluate investment decisions (TAUER, 2002). The *NPV* was calculated by the formula  $NPV = \frac{FV}{(1+i)^n}$  (BECHTEL *et al.*, 1995) where *FV* is the future value of money, *i* is the interest or discount rate, and *n* is the number of years.

The *CBR* is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream (GITTINGER, 1982) and can be obtained as follows (ERKUS and REHBER, 1998):

$$CBR = \frac{\sum_{t=0}^n R_t/q^t}{\sum_{t=0}^n C_t/q^t} \quad (1)$$

where *R* is the total revenue, *C* is the total cost, *i* is interest rate, and *n* is the number of years and  $q^t = (1+i)^t$ . If *CBR* > 1, then the total revenue is greater than the total cost, If *CBR* = 1 then the total revenue is equal to the total cost, and if *CBR* < 1 then the revenue is less than the total cost.

The internal rate of return (*IRR*) is a useful measure of project worth (GITTINGER, 1982) and helps to determine the relative profitability of an investment (BECHTEL *et al.*, 1995). *IRR* is discounted rate, which makes Net Cash Flows of the economic life of project zero (TAUER, 2000). The *IRR* formula is as follows:

$$IRR = r_1 + \frac{ND_1}{ND_1 + ND_2}(r_1 - r_2) \quad (2)$$

where *r*<sub>1</sub> is the last discount rate which makes *NPV* positive, *r*<sub>2</sub> is the first discount rate which makes *NPV* negative, *ND*<sub>1</sub> is the last positive *NPV*, *ND*<sub>2</sub> is the first negative absolute value of *NPV*.

Sensitivity analysis is described as a technique for measuring the impact on project, while changing one or key input values about which there is uncertainty (MARSHALL, 1999).

**Table 1:** The investment cost of the farms (\$/da)

<i>Items</i>	<i>Peach – year of establishment of production</i>				
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
Soil preparing and planting	74.1	—	—	—	—
Maintenance	15.5	75.8	48.4	70.2	52.7
Harvesting-Transporting	—	—	2.8	10.0	13.0
Various inputs *	221.9	33.6	18.5	33.1	21.4
Other expenses (5%) †	15.6	5.4	3.5	5.7	4.3
Total variable costs	327.1	114.8	73.2	119.0	91.5
Capital interest (10%) ‡	32.7	11.5	7.3	11.9	9.2
Land Rent	82.5	82.5	82.5	82.5	82.5
Management cost (3%) §	9.8	3.5	2.2	3.6	2.7
Total fixed costs	125.0	97.5	92.0	98.0	94.3
<b>Total</b>	<b>452.1</b>	<b>212.3</b>	<b>165.2</b>	<b>217.0</b>	<b>185.8</b>

<i>Items</i>	<i>Apple – year of establishment of production</i>						
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
Soil preparing and planting	25.5	1.1	1.1	1.1	1.1	1.1	1.3
Maintenance	9.4	22.6	27.4	20.5	37.5	38.1	45.0
Harvesting-Transporting	142.6	17.0	14.0	16.9	19.8	19.8	14.7
Various inputs *	—	—	—	—	—	—	22.7
Other expenses (5%) †	8.8	2.1	2.1	2.0	2.9	2.9	4.2
Total variable costs	186.3	42.8	44.6	40.5	61.3	61.9	88.0
Capital interest (10%) ‡	18.6	4.3	4.5	4.0	6.1	6.2	8.8
Land Rent	5.6	1.3	1.3	1.2	1.9	1.8	2.6
Management cost (3%) §	82.6	82.6	82.6	82.6	82.6	82.6	82.6
Total fixed costs	106.8	88.1	88.4	87.8	90.6	90.6	94.0
<b>Total</b>	<b>293.1</b>	<b>130.9</b>	<b>133.0</b>	<b>128.3</b>	<b>151.9</b>	<b>152.5</b>	<b>182.0</b>

\* Cover pesticide, fertilizer, irrigation and labor costs  
† The unexpected costs (transaction cost, transportation cost, labor and etc.), which occur during establishment period (ÇIÇEK *et al.*, 2001).  
‡ The interest rate of capital is 10 percent of total fixed establishment (AKÇAY *et al.*, 2004).  
§ Management cost is taken as 3 percent of total establishment cost (AKÇAY and UZUNÖZ, 1999).

### 3 Results and Discussion

Establishment cost is an investment that takes time to pay off (SHARP and COOLEY, 2004). The establishment costs of peach and apple production are given in Table 1.

As it can be seen from Table 2, the variable costs have a share of 65.0 percent for peach and 61.7 percent for apple in total production cost. With a 37.0 percent, maintenance

has the biggest share for peach and with a 23.0 percent, various inputs for apple in the variable costs.

As it can be seen from Table 3, the annual revenue of the producer is coming from the principal product and intermediary income.

**Table 2:** The production costs (\$/da).

<i>Items</i>	<i>Peach</i> <i>(year 6-20)</i>		<i>Apple</i> <i>(year 8-30)</i>	
	<i>(\$/da)</i>	<i>(%)</i>	<i>(\$/da)</i>	<i>(%)</i>
<i>Variable costs</i>				
Maintenance	133.4	37.0	45.1	15.0
Harvesting-Transporting	41.3	11.4	62.2	20.8
Various inputs	48.7	13.5	68.9	23.0
Other expenses (5%)	11.2	3.1	8.8	2.9
<b>Total Variable Costs (1)</b>	<b>234.6</b>	<b>65.0</b>	<b>185.0</b>	<b>61.7</b>
<i>Fixed costs</i>				
Capital interest (10%)	23.5	6.5	18.5	6.2
Management (3%) (*)	20.3	5.6	13.6	4.6
Land rent	82.5	22.9	82.5	27.5
<b>Total Fixed Costs (2)</b>	<b>126.3</b>	<b>35.0</b>	<b>114.6</b>	<b>38.3</b>
<b>Total Production Costs (1+2)</b>	<b>360.9</b>	<b>100.0</b>	<b>299.6</b>	<b>100.0</b>

\* Management cost is 3% of gross production value.

**Table 3:** Income in the farms (\$/da)

<i>Income particulars</i>	<i>Peach – year of production</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>year 6-20</i>
Principal product income	—	—	63.8	164.5	215.3	675.8
Intermediary income	123.3	23.7	98.4	—	—	—
<b>Total</b>	<b>123.3</b>	<b>23.7</b>	<b>162.2</b>	<b>164.5</b>	<b>215.3</b>	<b>675.8</b>

<i>Income particulars</i>	<i>Apple – year of production</i>							
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>year 8-30</i>
Principal product income	—	—	—	—	—	—	86.2	452.1
Intermediary income	206.1	23.7	123.3	164.5	23.7	215.3	37.2	—
<b>Total</b>	<b>206.1</b>	<b>23.7</b>	<b>123.3</b>	<b>164.5</b>	<b>23.7</b>	<b>215.3</b>	<b>223.4</b>	<b>452.1</b>



The Net Cash Flows are given in Table 4.

**Table 4:** Cash flows in the farms (\$/da)

<i>Income particulars</i>	<i>Peach – year of production</i>					
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6-20</i>
<i>Annual Farm Income</i>						
- Principal product income	—	—	63.8	164.5	215.3	675.8
- Intermediary income	123.3	23.7	98.4	—	—	—
<b>Total Farm Income</b>	<b>123.3</b>	<b>23.7</b>	<b>162.2</b>	<b>164.5</b>	<b>215.3</b>	<b>675.8</b>
<i>Annual Costs</i>						
- Investment costs	452.1	212.3	165.2	217.0	185.8	—
- Production costs	—	—	—	—	—	360.9
<b>Total Operation Costs</b>	<b>452.1</b>	<b>212.3</b>	<b>165.2</b>	<b>217.0</b>	<b>185.8</b>	<b>360.9</b>
<b>Cash Flows</b>	<b>-328.8</b>	<b>-188.6</b>	<b>-3.0</b>	<b>-52.5</b>	<b>29.5</b>	<b>314.9</b>

<i>Income particulars</i>	<i>Apple – year of production</i>							
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8-30</i>
<i>Annual Farm Income</i>								
- Principal product income	—	—	—	164.5	—	—	86.2	452.1
- Intermediary income	206.1	23.7	215.3	37.2	—	—	—	—
<b>Total Farm Income</b>	<b>206.1</b>	<b>23.7</b>	<b>123.3</b>	<b>164.5</b>	<b>23.7</b>	<b>215.3</b>	<b>223.4</b>	<b>452.1</b>
<i>Annual Costs</i>								
- Investment costs	293.1	130.9	133.0	128.3	151.9	152.5	182.0	—
- Production costs	—	—	—	—	—	—	—	299.6
<b>Total Operation Costs</b>	<b>452.1</b>	<b>212.3</b>	<b>165.2</b>	<b>217.0</b>	<b>151.9</b>	<b>152.5</b>	<b>182.0</b>	<b>299.6</b>
<b>Cash Flows</b>	<b>-87.0</b>	<b>-107.2</b>	<b>-9.7</b>	<b>36.2</b>	<b>-128.2</b>	<b>62.8</b>	<b>41.4</b>	<b>152.5</b>

The annual profits (cash flows) were calculated by subtracting the annual costs from annual revenue for a period of 20 years for peach and 30 years for apple (Table 4).

The establishment year is taken as a base and from the following year to the end of economic life was taken as production period. The choice of discount rate is determined by the investor's assumptions about inflation, risk and earning potential of other investments. If a producer is financing the investment internally, then the loan rate would be replaced by the producer's opportunity cost in the computation. Therefore different discount rates (10, 8 and 5%) were used in the study. *NPV* of the period was calculated and given in Table 5.

The *NPV* achieved for each discount rates are 1113.6 \$/da; 1454.7 \$/da; and 2156.2 \$/da, for peach respectively. The *NPV* achieved for each discount rates are 574.2 \$/da; 805.4 \$/da; and 1342.9 \$/da, for apple respectively.

**Table 5:** Cost–Benefit Ratio according to 10, 8 and 5 % discount rates.

<i>Peach</i>											
Year	Incomes (\$/da)		Costs (\$/da)		Discount rate 10%		Discount rate 8%		Discount rate 5%		Disc. Costs (\$/da)
			Discount	Disc. Income (\$/da)	Disc. Costs (\$/da)	Discount	Disc. Income (\$/da)	Disc. Costs (\$/da)	Discount	Disc. Income (\$/da)	
1	123.3	452.1	1	123.3	452.1	1	123.3	452.1	1	123.3	452.1
2	23.7	212.3	0.909	21.6	193.0	0.926	22.0	196.6	0.952	22.6	202.2
3	162.2	165.2	0.826	134.0	136.5	0.857	139.0	141.6	0.907	147.1	149.9
4	164.5	217.0	0.751	123.6	163.0	0.794	130.6	172.3	0.864	142.1	187.5
5	215.3	185.8	0.683	147.1	126.9	0.735	158.2	136.6	0.823	177.1	152.9
6-20	675.8	360.9	5.195	3510.7	1875.2	6.292	4251.7	2270.9	8.539	5770.8	3082.2
Total				4060.3	2946.7		4824.8	3370.1		6383.0	4226.8
NPV					1113.6			1454.7			2156.2
B/C					1.38			1.43			1.51
IRR							25.05				

<i>Apple</i>											
Year	Incomes (\$/da)		Costs (\$/da)		Discount rate 10%		Discount rate 8%		Discount rate 5%		Disc. Costs (\$/da)
			Discount	Disc. Income (\$/da)	Disc. Costs (\$/da)	Discount	Disc. Income (\$/da)	Disc. Costs (\$/da)	Discount	Disc. Income (\$/da)	
1	206.1	293.1	1	206.1	293.1	1	206.1	293.1	1	206.1	293.1
2	23.7	130.9	0.909	21.6	119.0	0.926	21.9	121.2	0.952	22.6	124.7
3	123.3	133.0	0.826	101.9	109.9	0.857	105.7	114.0	0.907	111.8	120.6
4	164.5	128.3	0.751	123.6	96.4	0.794	130.6	101.8	0.864	142.1	110.8
5	23.7	151.9	0.683	16.2	103.8	0.735	17.4	111.7	0.823	19.5	125.0
6	215.3	152.5	0.621	133.7	94.7	0.681	146.5	103.8	0.784	168.7	119.5
7	223.4	182	0.564	126.1	102.7	0.630	140.8	114.7	0.746	166.7	135.8
8-30	452.1	299.6	5.014	2266.9	1502.3	6.536	2954.7	1958.0	10.065	4550.5	3015.6
Total				2996.1	2421.9		3723.7	2918.3		5388.0	4045.1
NPV					574.2			805.4			1342.9
B/C					1.23			1.27			1.33
IRR							22.12				

*CBR* is calculated by dividing the total discounted incomes by the total discounted costs. The *CBR* in all the three discount rates is greater than 1 for peach and apple (Table 5). This means that the producer has a positive return in the production of peach and apple.

Internal rates of return (*IRR*) are given in Table 5. *IRR* was found as 25.05 percent for peach and 22.12 percent for apple, which are greater than the interest rate of capital. This means that the farmers were making more than two times of capital interest in the peach and apple production. Also the *IRR* was more than two times *IRR* (10.78%) AKÇAY and UZUNÖZ (2005) found for peach in Amasya in Middle Blacksea Region.

In the sensitivity analysis, three different *NPV*, *CBR* and *IRR* were found under the three different assumptions. When a 10 percent total cost overrun and 10 percent reduction of product price were assumed (Table 6), the *IRR*'s for peach decreased from

25.05 percent to 22.70 and 20.21 percent, respectively and the *IRR*'s for apple decreased from 22.12 percent to 16.25 and 15.57 percent, respectively. The results showed that the *IRR*'s for peach and apple are greater than the interest rate of capital.

In the light of the findings determined from the present study, it can be concluded that peach and apple farming can be one of the most important income sources for the fruit farmers of rural provinces of Tokat-Turkey.

**Table 6:** Sensitivity Analysis

<i>Peach</i>			
Assuming 10 percent higher total cost			
Discounted Rate (%)	10	8	5
<i>NPV</i> (\$)	819.3	1118.2	1735.0
<i>CBR</i>	1.25	1.30	1.37
<i>IRR</i> (%)	20.70		
Assuming 10 percent lower price of product			
Discounted Rate (%)	10	8	5
<i>NPV</i> (\$)	707.9	972.7	1518.5
<i>CBR</i>	1.24	1.29	1.35
<i>IRR</i> (%)	20.21		
<i>Apple</i>			
Assuming 10 percent higher total cost			
Discounted Rate (%)	10	8	5
<i>NPV</i> (\$)	331.8	513.2	937.8
<i>CBR</i>	1.12	1.16	1.21
<i>IRR</i> (%)	16.25		
Assuming 10 percent lower price of product			
Discounted Rate (%)	10	8	5
<i>NPV</i> (\$)	274.4	432.7	803.6
<i>CBR</i>	1.11	1.15	1.19
<i>IRR</i> (%)	15.57		

## References

- AKÇAY, Y. and UZUNÖZ, M.; Investment Analysis in the Fruits Plantations (A Case Study of Central District of Tokat Peach Orchards); *Journal of Faculty of Agriculture*; 6(1):99–117; 1999; ISSN 1300-2910, Tokat.
- AKÇAY, Y. and UZUNÖZ, M.; Investment Analysis of Peach and Cherry Growing in Turkey; *Journal of Applied Science*; 5(9):1665–1668; 2005.
- AKÇAY, Y., UZUNÖZ, M. and YANIK, T.; Investment Analysis of Salmonid Farming; *Indian Veterinary Journal*, India (in press); 2004.

- BECHTEL, L., BARRITT, B. H., DILLEY, M. A. and HINMAN, H. R.; *Economic Analysis of Apple Orchard Management Systems with Three Varieties in Central Washington*; Research Bulletin XB1032, Washington State University, 48 pg., USA; 1995.
- CASTLE, E. N., BECKER, H. M. and NELSON, A. G.; *Farm Business Management, Third Edition*; Macmillan Publishing Company, New-York, USA; 1987.
- ÇIÇEK, A., AKÇAY, Y., SAYILI, M. and UZUNÖZ, M.; A Comparative Economic Analysis Between Walnut and Its Alternative Crops in the Region (A Case Study of Niksar-Tokat-Turkey); *Acta Horticulturae*; 544:573–583; 2001; 4th Intern. Walnut Symposium, Bordeaux, France, 13-16 Sept. 1999.
- ENGINDENİZ, S., ÇUKUR, F. and ENGINDENİZ, D. Y.; Alternative Opportunities for Small Farms: A Case Study on Technical and Economic Analysis of Peach Growing in Turkey; *Journal of Agricultural & Food Information*; 5(4):47–58; 2004.
- ERKUS, A. and REHBER, E.; Proje Hazırlama Tekniği; Ankara Üniversitesi Ziraat Fakültesi Yayınları No: 1496, Ders Kitabı: 451, IV. Baskı, Ankara; 1998.
- GITTINGER, C. P.; *Economic Analysis of Agricultural Projects, Completely Revised and Expanded*; The Johns Hopkins University Press, Maryland, USA; 1982.
- HAKAN, E.; The Peach Industry in Turkey: State of Art, Research and Development; Mediterranean Peach Symposium, September 10th - Agrigento, Italy; 2003.
- KELSEY, M. and SCHWALLIER, P.; Cost of Producing Fresh Market Apples in Western Michigan 1998; Department of Agricultural Economics, Michigan State University, Staff Paper 99-43, 7 pg., East Lansing, Michigan, USA; 1999.
- MARINI, R. P.; Growing Peaches & Nectarines in Virginia; Virginia Cooperative Extension, Horticulture Publication 422-019, 6 pg., USA; 1997.
- MARSHALL, H. E.; Sensitivity Analysis; in: *Technology Management Handbook*, edited by DORF, R. C.; chap. 8.12, 8/59–63; CRC Press LLC; 1999.
- SHARP, R. and COOLEY, W.; The Cost of Growing Peaches in Western Colorado; Colorado State University, 17 pg., USA; 2004.
- SPO; Plant Production (Fruit) Special Commission Report, 8th Five-Year Development Plan; State Planning Organization (SPO), Publication No: SPO:2649, SCR:657, 753 pg., Ankara; 2001.
- SWINTON, S. M., BREMPONG, S. A. and VAN EE, G. R.; Investment Analysis of Alternative Fruit Tree Sprayers in Michigan Orchards; Michigan State University, Department of Agricultural Economics, East Lansing, MI 48824, USA; 1997.
- TAUER, L.; Investment Analysis in Agriculture; SP 2000-03, Dept. of Agric., Resource, and Managerial Economics, Cornell University, Ithaca, New York, 14853-7801, USA; 2000.
- TAUER, L. W.; Estimating Risk-Adjusted Interest Rates for Dairy Farms; *Agricultural Finance Review*; 62(1):59–68; 2002.

## Economic Assessment of Hazelnut Production and the Importance of Supply Management Approaches in Turkey

S. Göneç<sup>\*1</sup>, H. Tanrıvermiş<sup>2</sup> and M. Bülbül<sup>3</sup>

### Abstract

Turkey is the world's leading producer accounting for about 70% of world hazelnut supply. Hazelnut production is the single most important economic activity (monoculture) and income resource of rural households in the Black Sea Region. Hazelnut sector is supporting since 1962. However, due to inappropriate policies a stock problem has arisen in the sector. The Government has intervened to over production problem with various regulatory measures since 1989. However, results of supply response model showed that legal regulations have not any significant effect on reducing over production. Annual rate of increase of hazelnut production was calculated as 4.48%. And long term supply elasticity was found as 0.09 by Nerlove Model. The inelastic supply restricts the interventions on market by support price mechanism. However, high support prices and purchase guarantee keep farmers in hazelnut farming and encourage them to expand their production area. Monoculture is the most destructive factor which reduces all supply management initiatives. Government is both trying to keep farmers income at a certain level by high support prices, and also trying to apply supply control measures. This situation leads an intervention dilemma and creates a vicious cycle in hazelnut sector. Due to importance of Turkey in World hazelnut trade, it is necessary to solve over production problem in order to stabilize domestic and world prices. This research showed that the most effective way to supply control is to differentiate hazelnut farmer's income sources in order to encourage them to reduce their production area.

**Keywords:** hazelnut production, hazelnut policy, supply management, supply response

### 1 Introduction

Hazelnut was native to the black sea coast long before our era, not as a cultivated product but growing in the wild on trees or shrubs on the steep slopes of the mountains that are parallel to the coast for hundreds of kilometres from east to west. Hazelnut has

---

\* corresponding author

<sup>1</sup> Sertaç Göneç, Ph.D., Department of Agricultural Economics, Agricultural Faculty, Uludağ University, 16059, Gorukle, Bursa, Turkey; Tel: +90 224 442 89 70 (283), Fax: +90 224 442 80 77, e-mail: sduman@uludag.edu.tr

<sup>2</sup> Harun Tanrıvermiş, Associate Professor, Department of Agricultural Economics, Agricultural Faculty, Ankara University, Diskapi, Ankara, Turkey, e-mail: tanriver@agri.ankara.edu.tr

<sup>3</sup> Mehmet Bülbül, Professor, Department of Agricultural Economics, Agricultural Faculty, Ankara University, Diskapi, Ankara, Turkey, e-mail: bulbul@agri.ankara.edu.tr

been traded commercially for 600 years (ANONYMOUS, 2001). Hazelnut production is a traditional crop, grown for centuries on productive coastal, dry and marginal land largely concentrated in black sea region.

Hazelnut is not only one of the most important export crops of Turkey, but also the main economical activity of nearly 400,000 households under the form of family farming in the Black Sea Region (ANONYMOUS, 2001). These aspects of hazelnut production, which fall within the framework of multi-functionality, are seen as being the key factors in maintaining social, economic and environmental sustainability in the rural parts of the region as well as urban areas due to the employment and trade benefits created by hazelnut processing industry. The hazelnut economy directly and indirectly supports 8 million people. Therefore, stability of hazelnut prices is an important issue. However, price stability depends on stability of output or stability of volume offered for sale.

The control of output in agriculture is subject to two considerable obstacles, the effect of natural conditions and the large number of producers. In the field of agriculture, physical control is clearly very difficult. In the case of fruit, where the trees in any given season cannot be increased or decreased in number, the output, as far as the short time is considered, is almost completely beyond the control of the producer (WALLACE, 1951). Agricultural supply response is a very important issue in that it has an impact on growth, poverty and the environment. Agricultural supply response represents the agricultural output response to change in agricultural prices or to agricultural incentives (MAMINGI, 1997). The price of an agricultural commodity is the main factor that affects agricultural output. In general, many authors use some distributed lags to capture price expectation (BEHRMAN, 1968; BARITELLE and PRICE, 1974; BAPNA *et al.*, 1984; MSHOMBA, 1989; SHARMA, 1992; YAVUZ *et al.*, 2005). However, the lag structure may vary from one type of crop to another. Usually, one would expect perennial crops to have longer lags than annual crops. In some empirical studies, perennial crop supply was specified in terms of crop planting area and yield (BARITELLE and PRICE, 1974; CAMAN and GREEN, 1991; ALSTON *et al.*, 1995; ROSEEN, 1999). In this study, hazelnut supply was specified in terms of production quantity.

In this study, the economic structure of Turkish hazelnut sector and supply control strategies has been examined briefly. The description the model and the data used estimation of the model parameters was explained in the third section of the article and then, growing trend of hazelnut and factors affected hazelnut supply has been modelled and results were discussed in final section.

## **2 Economic Structure of Turkish Hazelnut Production**

The dynamics of world production and markets have not changed much in several decades. World hazelnut production in 2004 was 699,939 tones unshelled. Turkey is the largest producer (70%) and exporter of the world followed by Italy (12%), USA (5.7%) and Spain (2%). The world hazelnut production and export show fluctuations depending on the climatic conditions from year to year. World shelled hazelnut export is around 176,000 tones in 2004 and Turkey controlled 80 % of the commercial trade. The world supply of table hazelnut in shell does not exceed 15,000 tones, and the market is

saturated enough. Germany is the most important hazelnut importer in the world and covers approximately 36 % of the total world import. Around 75 % of total exports go to European countries and Europe consumes 80% of world production (MARTI, 2001; SHEPARD, 2002). In addition, Turkey is currently trying to expand the markets in Asia, Turkic Republics, and Russia.

In Turkey, hazelnut is produced approximately on 570,000 ha land (TANRIVERMIŞ *et al.*, 2006). Growers generally have very small plots. Most eastern producers have an orchard the size of only 1-2.5 ha; on the other hand, some central and western farmers have 10-15 ha orchards. According to the results of General Agricultural Census in 2001, average hazelnut farm size is 1.34 ha in general. Hazelnut farms are 4 times smaller than the average farm size of Turkey which is 6.1 ha (SIS, 2004).

Hazelnut production is the single income source of 61% of the families in the Black Sea Region (TANRIVERMIŞ *et al.*, 2006). Monoculture is a dominant character in hazelnut and tea production activities. The share of hazelnut production value in total provincial crop production value is 60,3% in Giresun, 57,8% in Ordu, 32,1% in Trabzon, 24,3% in Bolu, 17,6% in Sakarya, 9,2% in Zonguldak, 7,3% in Artvin, and 6,2% in Samsun. The production and market risks are relatively high particularly in Giresun and Ordu provinces where the share of hazelnut in total crop production value is more than 50%.

Most farmers are part-time farmer who grow hazelnuts to supplement their primary income, with less than the 1.5 hectares, and use family labour. This low-cost labour is the most important element in the production process to obtain much lower production costs (TANRIVERMIŞ and GÜNDOĞMUŞ, 2001; TANRIVERMIŞ *et al.*, 2004). Sloped land and labour are the main inputs of hazelnut production and there is a very limited possibility to employ these two inputs in any other alternative area.

Hazelnut production regions are separated into 3 groups in Turkey (AÇIL, 1963; SARI-MEŞELİ, 1992; TANRIVERMIŞ, 1991; GENÇ, 1993; ANONYMOUS, 2001). The first standard production region covers the eastern part of the Black Sea Region. This region is also called as “old hazelnut production region”. The second standard production region is the middle and western part of the black sea area. In this region, the hazelnut production history goes back to 40-50 years, thus the orchards are younger and more planned than the first standard region. Average yield of plantations is also higher in this region, and it leads to a rapid increase in production areas. The third region includes the other provinces where hazelnut grows (especially Bursa and Istanbul). The third region is not valuable for exporting and the most of products which are grown in this region is consumed without processing.

Hazelnut is produced in 33 provinces of Turkey, but economical production is realized by 13 provinces, which are located mostly in the first region. During the last 50 years while hazelnut production areas increased 2.5 fold, production quantity increased 200 fold (ANONYMOUS, 2001; TANRIVERMIŞ *et al.*, 2006).

### 3 Supply Control Strategies for Hazelnut Farming in Turkey

Due to socio-economic importance of the crop, hazelnut production has important political implications in Turkey. Hazelnut has been included to support program in 1962. In the past, the Turkish government has supported prices for hazelnut production by providing funds to Fiskobirlik (Union of Hazelnut Sales Cooperatives). Fiskobirlik has historically served as a conduit for Turkey's government policy decisions. As a result of historically high support prices, hazelnut area and production expanded. Hazelnut prices show variation through years. The pricing of the regulated product frequently occurs in political atmosphere (VAN KOOTEN and TAYLOR, 1989) and it makes more difficult to regulate the market. Free market prices are generally lower than Fiskobirlik's price. When stock quantity is high, free market prices go down up to 40% below than support price. Fluctuating prices damage farmer's income directly.

The domestic consumption quantity of hazelnut is not known due to lack of data. However, this amount is predicted approximately 35,000 tones per year (TANRIVERMIŞ *et al.*, 2006). Hazelnut production, export, domestic consumption and stock data have been given in Table 1. As an average 143,804 tones of hazelnut surplus had to be stocked every year. As a result of inappropriate policies since 1923, hazelnut production areas shifted from sloped areas to first and second class farmlands and over expansion in production area could not be controlled.

**Table 1:** Hazelnut production, export, domestic consumption and stocks of Turkey

Years	Production (tone/in shell)	Export (tone/shelled)	Domestic Consumption (tone/shelled)	Stock (tone/in shell)	Ratio of Stocks in Production (%)
1980	302,461	99,219	16,500	37,350	12.35
1985	179,739	108,315	30,000	52,999	24.59
1990	374,566	195,645	30,000	272,296	72.70
1995	474,044	241,436	30,000	61,851	13.05
2000	467,719	177,307	35,000	273,871	58.55
2001	618,919	258,124	40,000	203,145	32.82
2002	620,000	252,779	40,000	229,904	37.08
2003	450,000	220,938	35,000	189,676	42.15
Average of 1964-2003	324,277	140,079	28,521	143,804	% 41

Source: (TANRIVERMIŞ *et al.*, 2006)

Supply management has to be applied in order to cope with excess supply problem. Supply management has referred to a variety of systems to decrease supplies from government purchasing of surplus stocks to providing financial incentives to reduce production (LEVY, 2000). In general, supply control measures can be listed as; import control, government purchasing of surplus stocks, acreage controls, providing financial incentives to reduce production, and use of quotas that assign a given amount of product to each (BRANDOW, 1960; VAN KOOTEN and TAYLOR, 1989; USDA, 1999; LEVY, 2000). Different kinds of supply control methods were implemented especially by Canada, the EU member states and USA up to date (MOSCHINI, 1988; USDA, 1999; TOLMAN, 2002).



In general, import restriction is the first step in supply control. However, in Turkish hazelnut sector there is already no significant import. Thus this measure is not valid for this sector.

In Turkish hazelnut sector a combination of supply control methods have been applied in different periods. These are summarized below:

Government purchasing of surplus stocks; Fiskobirlik is the most important organization of the sector and it aims to stabilize hazelnut prices by withdrawing the surplus product. Fiskobirlik support policy is to buy unlimited quantities of product from producers with an intervention price which is fixed for each production year. However, today the funds of and quantity purchased by Fiskobirlik has reduced. In 2000, the Turkish government reorganized the activities of Agricultural Sale Cooperatives including Fiskobirlik by giving them autonomy and separating their procurement and processing functions by the law of Agricultural Sales Cooperatives and Unions Nr. of 4572 (TANRIVERMİŞ *et al.*, 2006; USDA, 2005). Starting in 1999, with pressure from the World Bank and International Monetary Fund (within the framework of agricultural reform implementation project (ARIP) and stand-by agreement), Turkey has progressively reduced these intervention prices.

Acreage control is a widespread method that governments of many countries resort to in order to cope with over-production. The Turkish Government made a number of legal arrangements in order to regulate and control hazelnut production. A law number of 2844 "Planning of Hazelnut Production and Determination of Hazelnut Production Areas" dated 1983 put into practise and the regulation on "Planning of Hazelnut Production and Determination of Hazelnut Production Areas" came into force in 1989. On 3 February 1993 hazelnut plantation areas were restricted with 13 provinces by the Decision Nr. 93/3985 of Ministry Council. Hence, the plantation of new hazelnut orchards is subject to official permission.

In 1994, Government was decided to pay compensation to the farmers who remove their own hazelnut orchards before completing their economical life by Decision Nr.94/6519. This Decision covers the farmers who have orchards in the first and second classes agricultural lands and in the third class agricultural lands that have less than 6% slope in the provinces that were permitted by Decision Nr. 93/3965.

The farmers were also encouraged to grow other alternative products. In this respect, the Decision Nr. 24382, "Determination of Hazelnut Production Areas and Supporting the Farmers who Remove their Hazelnut Orchard and Plant any Alternative Product instead of Hazelnut" was published and came into force in 2001.

Production quotas have not implemented in the sector yet. Production quotas have been implemented for a long time on some annual crops such as sugar beet, and tobacco in Turkey.

Storage would also be desirable to assure adequate market supplies in years of short crops. Thus storage program to stabilize annual supplies would be one adjunct to supply control (BRANDOW, 1960). However for perennial crops, storage would not be an appropriate policy tool for controlling and eliminating overproduction in short-term

due to the long productive life of plants. In fact, the conditions of storage facilities may cause high level losses and increase production cost. In reality, storage of hazelnut in the region is not seen as a suitable policy of supply control due to the technical and economic consequences.

In some countries there is too much supply control, but not enough demand control. In Turkey, Hazelnut Promotion Group (HPG) has been established with the joint initiatives of Fiskobirlik, Undersecretariat of Treasury and Black Sea Chambers of Exporters. The main objective of HPG was to promote both domestic and international demand of hazelnut. With this purpose, the Group has prepared generic advertising program and applied a common promotion plan. The first result of hazelnut promotion was good and it was declared that 30% demand increase was observed in new foreign markets after a year of promotion (ANONYMOUS, 2002).

#### 4 Data and the Models

The data used in the study were obtained from various publications of the State Institute of Statistics (SIS) of Turkey and Fiskobirlik's publications. The time series data covers the period between 1950 and 2004. Data set was also arranged according to each Standard Production Region as both time series and panel data.

Trend equation and annual average rate of increase for production area, quantity and yield was estimated by using equation (1) (SNEDECOR and COCHRAN, 1980; ERTEK, 1987; GÜNES and ARIKAN, 1988).

$$W = ab^t \quad (1)$$

Where  $a$  and  $b$  are constants to be estimated and  $t$  denotes time.

Applying logarithms to the equation results:

$$\log W = \log a + (\log b)t \quad \text{or} \quad (2)$$

$$Y = \alpha + \beta t \quad (3)$$

where:  $Y = \log W$ ;  $\alpha = \log a$  and  $\beta = \log b$ . If  $\log W$  instead of  $W$  is plotted against  $t$ , the graph will be linear.

This equation was used for three data sets respectively:  $Y_a$  denotes production area (ha),  $Y_q$  is production quantity (tonne) and  $Y_y$  is yield (kg/ha). Coefficients were estimated by SPSS 11.5 statistical package program.

Regional differences in production area, quantity and yield according to three standard production regions were determined by using dummy variables. ANOVA model was used for this purpose. In this model, panel data set was used in order to reduce the effect of time (GUJARATI, 1992; BALTAGI, 1996). The model is given below:

$$Y_i = \alpha_1 + \alpha_2 D_2 + \alpha_3 D_3 + u \quad (4)$$

where:

$Y_i$ : production area, quantity and yield respectively,

$D$ : dummy variable:

$$D_2 = \begin{cases} 1 & : \text{(if 2}^{nd} \text{ Region)} \\ 0 & : \text{(other)} \end{cases} \quad D_3 = \begin{cases} 1 & : \text{(if 3}^{rd} \text{ Region)} \\ 0 & : \text{(other)} \end{cases}$$

and  $\left(\frac{\alpha_t}{\alpha_1}\right)$  denotes changing ratio according to the regions.

In the supply response model, total production quantity ( $Q_t$ ) has been taken as dependent variable. Price is compatible with supply theory and is therefore used as the independent variable. Plantation of new trees is the function of future expected prices. Future expected prices were a function of a finite number of past prices (BARITELLE and PRICE, 1974). Thus, lagged prices were included in the model. The length of the individual past years price lag left to statistical estimation process.

There are two different prices valid in hazelnut sector; support price ( $SP$ ) which is declared by the government via Fiskobirlik and free market price ( $FM$ ) which is constituted around support price. Correlation between the two prices is high (0.80). This high correlation coefficient may cause an imperfect multicollinearity problem in the model, if both of them are used together as independent variables. For this reason, only support price was included the model.

Support purchase, export and stock quantities and export price have been taken as independent variables. These variables were used in the model with one year lagged values. Weather conditions and regulatory supply management measures have been used as dummy variables. Among agro climatic factors, freeze is likely to be the most decisive for hazelnut supply response.

Data set has covered the period between 1950 and 2004. Consumer Price Index ( $CPI$ ) was used to obtain real price level. The real prices are given as:

$$P^R = \frac{CPI_b}{CPI_c} \times P_c \quad (5)$$

where  $P^R$  is real price,  $CPI_c$  is the current year's consumer price index,  $CPI_b$  is the base year consumer price index and  $P_c$  is the current price.

$$Q_t = a + b_1 SPQ_{t-1} + b_2 EQ_{t-1} + b_3 \frac{EP_{t-1}}{CPI} + b_4 S_{t-1} + \sum_{n=5}^{11} b_n \sum_{t=1}^T \frac{SP_{t-T}}{CPI} + b_{12} D_{FR} + b_{13} D_{89} + b_{14} D_{93} + b_{15} D_{94} + b_{16} D_{01} + e \quad (6)$$

where:

$SPQ$ : support purchase quantity (tone/year)

$EQ$ : export quantity (tone/year)

$EP$ : export price (\$/tone)

$S$ : annual stock quantity (tone/year)

$SP$ : Support Price (TL/kg)

$D_{FR}$ : Dummy, freeze

$D_{89}$ : Dummy, year 1989, regulation on determination of hazelnut production areas

$D_{93}$ : Dummy, year 1993, regulation on restriction of hazelnut production areas

$D_{94}$ : Dummy, year 1994, regulation on compensation of producers

$D_{01}$ : Dummy, year 2001, regulation on alternative crop

The long run supply elasticity was calculated by Nerlove's supply response model. The Model consists of the three equations:

$$A_t^* = \alpha_0 + \alpha_1 P_t^* + u_t \quad (7)$$

$$P_t^* = P_{t-1}^* + \beta(P_{t-1} - P_{t-1}^*) \quad (8)$$

$$A_t = A_{t-1} + \gamma(A_t^* - A_{t-1}) \quad (9)$$

where  $A_t$  and  $A_t^*$  are actual and desired area under cultivation at time  $t$ ,  $P_t$  and  $P_t^*$  are actual and expected price at time  $t$  and  $\beta$  and  $\gamma$  are the expectation and adjustment coefficients, respectively. Elimination of the unobservable variables  $A_t^*$  and  $P_t^*$  leads immediately to the reduced form:

$$A_t = b_0 + b_1 P_{t-1} + b_2 A_{t-1} + b_3 A_{t-2} + u_t$$

with  $b_0 = \alpha_0 \beta \gamma$ ,  $b_1 = \alpha_1 \beta \gamma$ ,  $b_2 = (1 - \beta) + (1 - \gamma)$ ,  $b_3 = -1(1 - \beta)(1 - \gamma)$  and  $u_t = \gamma(u_{t-1} - (1 - \beta)u_{t-2})$  from which the key parameter  $\alpha_1$  may be retrieved by means of the identity  $\alpha_1 = b_1(1 - b_2 - b_3)$ . The long term price elasticity  $\varepsilon$  is then usually calculated as

$$\varepsilon = \alpha_1 \frac{\bar{P}}{\bar{A}} = \frac{b_1 \bar{P}}{(1 - b_2 - b_3) \bar{A}}$$

where  $\bar{P}$  and  $\bar{A}$  represent historical mean of prices and acreage under cultivation, respectively (NERLOVE and ADDISON, 1958; BRAULKE, 1982; BEGUM *et al.*, 2002).

## 5 Results and Discussion

According to calculated trend results (Table 2), annual average increase rate of hazelnut production areas, production quantity and yield of Turkey are; 1.79%; 4.48% and 1.30% respectively. Difference between hazelnut production regions is statistically important (Table 3) and the highest increase rate of production area and quantity is observed in second production region. This region stimulates Turkish hazelnut production increase and it is recommended that the main supply control mechanism should be intensively applied in this region.

Results of supply response model (Table 4) showed that while one year lagged export price and four years lagged support price increase hazelnut production, one year lagged stock quantity and negative weather conditions (freeze) decrease hazelnut production. BARITELLE and PRICE (1974) found the lag length as 8 years for apples. YAVUZ *et al.* (2005) found the lag length as 5 years for hazelnut supply response. THIELE (2002) indicate that negative weather conditions are very important in supply response. In his study, it was found that among the non-price factors, freeze has significantly impaired agricultural growth.

**Table 2:** Trends according to regions ( $W = ab^t$ )

	<i>Turkey</i>	<i>Region 1</i>	<i>Region 2</i>	<i>Region 3</i>
<i>Production area (ha)</i>				
<i>log a</i>	5.1450*	5.1340*	4.0500*	2.2750*
<i>A</i>	139636.8200	136144	11220	188.3600
<i>log b</i>	0.0077*	0.0037*	0.0225*	0.0191*
<i>B</i>	1.0179	1.0080	1.0530	1.0450
<i>R</i> <sup>2</sup>	0.934	0.6480	0.9500	0.8140
<i>F</i>	706.2500	91.9800	950.4850	218.7400
<i>Production quantity (tonne)</i>				
<i>log a</i>	4.8140*	4.7510*	3.9550*	2.4290*
<i>A</i>	65162.8300	56363	9015	268.5300
<i>log b</i>	0.0190*	0.0149*	0.0307*	0.0196*
<i>B</i>	1.0448	1.0350	1.0730	1.0460
<i>R</i> <sup>2</sup>	0.7960	0.6540	0.8790	0.8670
<i>F</i>	195.6040	94.6560	363.1790	326.1960
<i>Average yield (kg/ha)</i>				
<i>log a</i>	1.9520*	1.6170*	1.9050*	2.1540*
<i>A</i>	89.5400	41.3900	80.3500	142.5600
<i>log b</i>	0.0054*	0.0112*	0.0082*	0.0005
<i>B</i>	1.0130	1.0260	1.0190	1.0000
<i>R</i> <sup>2</sup>	0.4380	0.5130	0.4150	0.0040
<i>F</i>	38.8920	52.7070	35.4180	0.1940

\* Statistically significant at 1 % level

**Table 3:** Regional differences (ANOVA Model)

	$\alpha_1$	$\alpha_2$	$\alpha_3$	<i>R</i> <sup>2</sup>	<i>F</i>
Production Area ( $Y_a$ )	171379.29*	-115247.40*	-166764.30*	0.83	382.74
Production Quantity ( $Y_{ii}$ )	161040.40*	-71018.54*	-159960.00*	0.50	77.40
Average Yield ( $Y_v$ )	91.27*	50.38*	60.94*	0.24	24.11

\* Statistically significant at 1 % level

**Table 4:** Estimated results for supply response model

<i>Variables</i>	$\beta$	<i>Std. Error</i>	<i>t</i>	<i>Sig.</i>
Constant	57723,353	22342.681		2.584
<i>SPQ</i>	2847,738	7486.179	0.049	0.380
<i>EQ</i>	0.050	0.200	0.043	0.250
<i>EP</i>	102.151	34.287	0.354	2.979
<i>S</i>	-0.287	0.128	-0.162	-2.236
<i>D<sub>FR</sub></i>	-63702.145	24943.492	-0.176	-2.554
<i>D<sub>89</sub></i>	62078.408	38387.735	0.175	1.617
<i>D<sub>93</sub></i>	62186.578	77123.487	0.159	0.806
<i>D<sub>94</sub></i>	-80697.257	69713.878	-0.199	-1.158
<i>D<sub>01</sub></i>	52549.674	67916.597	0.088	0.774
<i>SP<sub>lag1</sub></i>	-5041.928	10224.583	-0.084	-0.493
<i>SP<sub>lag2</sub></i>	9124.270	8867.255	0.156	1.029
<i>SP<sub>lag3</sub></i>	-7714.978	8786.891	-0.135	-0.878
<i>SP<sub>lag4</sub></i>	22539.579	9562.314	0.399	2.357
<i>SP<sub>lag5</sub></i>	4370.888	10291.200	0.078	0.425
<i>SP<sub>lag6</sub></i>	-6539.788	10493.394	-0.111	-0.623
<i>SP<sub>lag7</sub></i>	10424.781	8511.224	0.166	1.225

According to results of supply response model, regulatory measures of government have not any significant effect on supply control.

Formulation of an appropriate agricultural price policy for growth and stability requires an understanding of the long term effects of price changes upon producers and consumers (NERLOVE and ADDISON, 1958). Long term supply elasticity of hazelnut production was found as 0.09 by using the Nerlove Model. This highly inelastic supply showed that overproduction can not be explained only high support prices and price control will not be very effective in controlling output. On the other hand it is a fact that a historically high support price is the most important reason which promotes small-scale farmers to continue their production.

There is an intervention dilemma in hazelnut sector. Turkish Government has tried to apply both support and supply control mechanisms at the same time. It was necessary to support prices in order to keep farmer's income at a certain level. On the other hand long term support policies stimulate overproduction and depressed prices. Depressed prices forced Government to support farmers again and this situation has created a vicious cycle in the sector. The base of the problem is monoculture. Small scale farmers

have no other alternative except for hazelnut farming and they had to increase their production area in order to increase their family income.

Recent years, Turkish Government has begun to reduce its interventions and support prices by the conditions of ARIP and stand-by agreements under the auspices of IMF and the World Bank. However due to explanations above it is expected that reduced support prices will not do any important implication on over supply.

Actually government intervention may be sufficient to prevent the over production under monopoly conditions (VAN KOOTEN and TAYLOR, 1989). But the hazelnut sector does not have a monopoly character and there are two prices and alternative sale options in the market as mentioned before.

This results show that the best way to break this vicious cycle and cope with over supply problem is to create new agricultural and/or off-farm income sources. In this respect, incentives and encouragement to organic hazelnut production is accepted as another way to control supply. According to the research results carried out at farm level, transition to organic industry from conventional farming is economically, socially and ecologically viable. It is interesting that average yield and net profit per hectare of planted land is higher than conventional farming in the region (BÜLBÜL, 2002). In addition to the development of organic industry in the region, cultivation of some new crops should be encouraged on farms within the framework of agricultural and rural policies. Hazelnut growers have a tendency to adopt kiwifruit plantation on farms and the research results indicated that labour requirements, gross and net profit per planted area of kiwifruit is more than and hazelnut farming (TANRIVERMİŞ *et al.*, 2006). In fact, the development of new cultivation should be parallel to the domestic and external demand in order to solve surplus of products.

An appropriate alternative is to provide incentives for non-farm activities of hazelnut producers' in order to develop agricultural and non-agricultural activities such as rural tourism, rural industrialization, handicraft activities and agricultural activities other than hazelnut growing like fisheries, forest products and animal products production etc. in the region. Therefore, improvement of living standards and/or stabilization of farm/household incomes should be achieved through differentiations of income sources. Through these means, dependency of economic and social life on hazelnut farming, processing and trade will be decreased and the impacts of monoculture will be mitigated.

## References

- ALSTON, J. M., CARMAN, H. F., CHRISTIAN, J. E., DOREMAN, I., MURUA, J. R. and SEXTON, R. J.; *Optimal Reserve and Export Policies for California Almond Industry: Theory, Econometrics and Simulations*; no. 42 in Giannini Foundation Monograph; Division of Agriculture and Natural Resources, California Agricultural Experiment Station, Davis; 1995.
- ANONYMOUS; Sekizinci Bes Yillik Kalkinma Planı Bitkisel Üretim Özel İhtisas Komisyonu Meyvecilik Alt Komisyonu Raporu; DPT: 2649 - ÖİK:657, Ankara; 2001.

- ANONYMOUS; "Her Çinliye Bir Fındık"; Turkishtime, September, Nr. 8, Publication of the Turkish Exporters Assembly; 2002.
- AÇIL, A. F.; Türkiye Ekonomisinde Fındık ve Giresun Fındık İşletmeleri; A.Ü. Ziraat Fakültesi Yayınları: 215, Ankara; 1963; (in Turkish).
- BALTAGI, B. H.; *Econometric Analyses of Panel Data*; John Wiley&Sons, England; 1996.
- BAPNA, S. L., BINSWANGER, H. P. and QUIZAN, J. B.; Systems of output supply and factor demand equations for semi arid tropical India; *Indian Journal of Agricultural Economics*; 39:179–213; 1984.
- BARITELLE, J. L. and PRICE, D. W.; Supply Response and Marketing Strategies for Deciduous Crops; *American Journal of Agricultural Economics*; 56:245–253; 1974.
- BEGUM, M. A. A., FAKHRUL ISLAM, S. M. KAMRUZZAMAN, M., KABIR, M. J. and SHIBLEE, S. M. A.; Supply Response of Wheat in Bangladesh: An Application of Partial Adjustment Model; *Pakistan Journal of Biological Sciences*; 5(2):225–229; 2002.
- BEHRMAN, J. R.; Monopolistic Cacao Pricing; *American Journal of Agricultural Economics*; 50:702–719; 1968.
- BRANDOW, G. E.; Supply Control: Ideas, Implications and Measures; *Journal of Farm Economics*; 42(5):1167–1180; 1960.
- BRAULKE, M.; A Note on the Nerlove Model of Agricultural Supply Response; *International Economic Review*; 23(1):241–244; 1982.
- BÜLBÜL, M. UND TANRIVERMİS, H.; Vergleichende wirtschaftliche Analyse des konventionellen und ökologischen Haselnussanbaus in der Türkei; *Berichte über Landwirtschaft*; 80(2):304–320; 2002.
- CAMAN, H. F. and GREEN, R. D.; Commodity Supply Response to a Producer Advertising Programme: The California Avocado Industry; Manuscripts, Department of Agricultural Economics, University of California, Davis; 1991.
- ERTEK, T.; Ekonometriye Giriş; Beta Basım Yayım Dağıtım, İstanbul; 1987.
- GENÇ, K. S.; Ünye İlçesi Fındık Üreticilerinin Sosyo-ekonomik Yapısı; Ankara Üniversitesi Fen Bilimleri Enstitüsü, Tarım Ekonomisi Anabilim Dalı Doktora Tezi, Ankara; 1993; (in Turkish).
- GUJARATI, D.; *Essentials of Econometrics*; McGraw Hill, USA; 1992.
- GÜNES, T. and ARIKAN, R.; Tarım Ekonomisi İstatistigi; A.Ü. Ziraat Fakültesi Yayınları: 1049, Ders Kitabı: 305, Ankara; 1988; (in Turkish).
- VAN KOOTEN, G. C. and TAYLOR, K. F.; Measuring the Marginal Welfare Impacts of Government Regulation: The Case of Supply Management; *The Canadian Journal of Economics*; 22(4):892–903; 1989.
- LEVY, B.; When the Farmer Makes the Rules; The Journal of the New Rules Project, Fall 2000; 2000.
- MAMINGI, N.; The Impact of Prices and Macroeconomic Policies on Agricultural Supply: a Synthesis of Available Results; *Agricultural Economics*; 16:17–34; 1997.
- MARTI, J. T.; World Hazelnut Production; Ninth Australasian Conference on Trees and Nut Crops, April 13–20, 2001, Perth, Western Australia; 2001.



- MOSCHINI, G.; A Model of Production with Supply Management for the Canadian Agricultural Sector; *American Journal of Agricultural Economics*; 70(2):318–329; 1988.
- MSHOMBA, E. R.; Price elasticity of supply of Tanzania's major export crops; *Eastern African Economic Review*; 5:9–20; 1989.
- NERLOVE, M. and ADDISON, W.; Statistical Estimation of Long Run Elasticities of Supply and Demand; *Journal of Farm Economics*; 40:861–880; 1958.
- ROSEEN, J.; A Regional Econometric Model of U.S. Apply Supply and Demand; Department of Economics, Iowa State University, Ames, USA, Staff Paper No: 317; 1999.
- SARIMEŞELİ, M.; Fındık Dikim Alanları Projesi: Nihai Rapor; Gazi Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, Ankara; 1992; (in Turkish).
- SHARMA, K. L.; Aggregate Farm Supply Response in Kenya; *Eastern African Economic Review*; 8:92–101; 1992.
- SHEPARD, M., .; The Present World Hazelnut Industry; Badgersett Research Corporation, pp.28, USA; 2002.
- SIS; General Agricultural Census 2001 - Results of the Agricultural Holdings (Households) Survey; State Institute of Statistics, Publication Number: 2924, Ankara; 2004.
- SNEDECOR, G. and COCHRAN, W. G.; *Statistical Methods, Seventh Edition*; The Iowa State University Press; 1980.
- TANRIVERMİŞ, H.; Hazelnut Production, Some Economic Factors Affecting the Production and Evaluation of Production Policy in Turkey; *Cooperation Quarterly Cooperative Research Journal*; 95:63–74; 1991.
- TANRIVERMİŞ, H., GÖNENÇ, S., TERZIOĞLU, S. B. and ŞANLI, H.; Socio-economic Aspects, the Results of the Applied Policies and Main Problems of Hazelnut Production in Turkey; Türkiye 3. Milli Fındık Surasi, 10-14 Ekim 2004, Giresun, pp.125-145; 2006; (in Turkish).
- TANRIVERMİŞ, H. and GÜNDOĞMUŞ, E.; Doğrudan Gelir Desteği Uygulaması İçin Baslangıç Verileri (Baseline) Olusturma ve Pilot Uygulamanın Değerlendirilmesi: Trabzon İli Örneği; in: *Doğrudan Gelir Desteği Uygulamasının İzleme ve Değerlendirmesi*, edited by BAYANER, A., KOÇ, A., TANRIVERMİŞ, H., GÜNDOĞMUŞ, E., ÖREN, N. and ÖZKAN, B.; 99–132; TEAE Yayın No:57, Ankara; 2001; (in Turkish).
- TANRIVERMİŞ, H., GÜNDOĞMUŞ, E. and DEMIRCI, R.; Appraisal of Expropriation Value of Farmland; EDUSER Education and Consultancy Services Co., Ankara; 2004.
- THIELE, R.; Price Incentives, Non-price Factors and Agricultural Production in Sub-Saharan Africa: A Cointegration Analysis; Kiel Institute for World Economics, Working Paper No: 1123, Germany; 2002.
- TOLMAN, J.; Agricultural Subsidies, Consumer Take Charge Agenda for the 104th Congress; Issue Brief, USA; 2002.
- USDA; The EU's Agricultural Policy Instruments, Agricultural Outlook; December 1999, USA; 1999.
- USDA; Hazelnut Situation and Outlook in Selected Countries; FAS Online, Horticultural and Tropical Products Division. USA; 2005.

- WALLACE, D. H.; Price Control and Rationing; *The American Economic Review*; 41:60–62; 1951.
- YAVUZ, F., BIRINCI, A., PEKER, K. and ATSAN, T.; Econometric Modelling of Turkey's Hazelnut Sector: Implications on Recent Policies; *Turk J. Agr. For.*; 29:1–7; 2005.

## Crop Coefficient of Haricot Bean at Melkassa, Central Rift Valley of Ethiopia

Samson Laike<sup>1</sup>, Ketema Tilahun<sup>2\*</sup> and Tilahun Hordofa<sup>3</sup>

### Abstract

Crop coefficient ( $K_c$ ), the ratio of potential crop evapotranspiration to reference evapotranspiration, is an important parameter in irrigation planning and management. However, this information is not available for many important crops. A study was carried out at the experimental farm of Melkassa Agricultural Research Center of Ethiopian Agricultural Research Organization, which is located in a semi arid climate. Four drainage type lysimeters were used to measure the daily evapotranspiration of haricot bean, *Awash Melka* variety on a clay loam soil. Crop coefficient was developed from measured crop evapotranspiration and reference evapotranspiration calculated using weather data. The measured values of crop coefficient for the crop were 0.34, 0.70, 1.01 and 0.68 during initial, development, mid-season and late-season stages. These locally determined values can be used by irrigation planners and managers at Melkassa and other areas with similar agroecological conditions.

**Keywords:** crop coefficient, Ethiopia, haricot bean, lysimeter

### 1 Introduction

Decisions related to agricultural water management such as irrigation scheduling, water resources allocation and planning require the information about the water loss for a given crop. This water loss from a given cropped plot of land can be determined from the knowledge of reference evapotranspiration ( $ET_o$ ), potential evapotranspiration ( $ET_c$ ), and crop coefficient ( $K_c$ ).

Most methods of estimating evapotranspiration involve two steps; first, evapotranspiration for a well watered reference crop (grass or alfalfa) with standard canopy characteristics ( $ET_o$ ) is estimated (BURMAN *et al.*, 1980; DOORENBOS and PRUITT, 1977). Currently, the FAO Penman-Monteith method is recommended to estimate  $ET_o$  (ALLEN *et al.*, 1998). Then evapotranspiration for the crop being considered ( $ET_c$ ) is obtained by multiplying  $ET_o$  by a crop coefficient ( $K_c$ ) which varies by growth stage for each crop.

---

<sup>1</sup> Kombolcha Agricultural Technical and Vocational Education Training College, Ethiopia

<sup>2</sup> P.O. Box 45, Alemaya University, Ethiopia; fax: 0251-5-610713,  
email: ketematilahun@yahoo.com

\* corresponding author

<sup>3</sup> Melkassa Agricultural Research Center, Ethiopia

Crop coefficient represents crop specific water use and is essential for accurate estimation of irrigation requirement of different crops in the command area. It serves as an aggregation of the physical and physiological differences between crops and the reference definition. The variation of the crop coefficient during a growing season is obtained experimentally (BURMAN *et al.*, 1980; DOORENBOS and PRUITT, 1977; JENSEN, 1974; PRUITT *et al.*, 1972, 1987; WRIGHT, 1982). Although there are published  $K_c$  values for different crops, these values are commonly used in places where local data are not available. As these values vary from place to place and from season to season, there is a strong need for local calibration of crop coefficients under given climatic conditions (TYAGI *et al.*, 2000). There is, therefore, a pressing need to experimentally measure crop coefficients locally, so that project managers can correctly be advised.

Haricot bean (*Phaseolus vulgaris*), the subject crop of this research, is a well-established component of Ethiopian agriculture. From the export of white seeded beans, Ethiopia on average obtains about 16 million USD, out of which Awash Melka, the famous exportable variety used in this study, contributes the major portion (MARC, 2001). The middle rift valley of Ethiopia contributes about 60% of haricot bean production in the country. However, unreliable and poor distribution of rain is one of the major causes for low yield of haricot bean in this area (IAR, 1990). At present, farmers are opting for the production of this crop under irrigation. However, the water requirement data and crop coefficient of this crop is not locally available. Hence, knowledge of experimentally determined  $K_c$  value is important for proper irrigation scheduling and efficient water management of the selected crop variety. Therefore, this study was undertaken with the objective of developing crop coefficient for different growth stages of haricot bean.

## 2 Materials and Methods

### 2.1 General description of the study area and experimental lysimeters

This research was conducted on four lysimeters at Melkassa Agricultural Research Center, Central Rift Valley of Ethiopia. The center is located at an elevation of 1550 m above sea level with latitude of 8°24' N and longitude of 39°21' E. The average annual rainfall in the area is 768 mm, which is erratic and uneven in distribution. The site has a mean maximum temperature of 28.5°C and mean minimum temperature of 12.6°C. Loam and clay loam soil textures are the dominant soils of the area.

The experimental lysimeters are located near the agrometeorological station of the research center. The lysimeters were of non-weighing type each having an access chamber for aeration and underground steel pipes for disposal of drainage water from the lysimeters. These pipes are connected to water collecting tank mid way between the four lysimeters. Rim of each lysimeter protruded 10 cm above the soil surface so that no surface water runoff may occur. One access tube for each lysimeter was installed at the center down to 90 cm depth.

### 2.2 Crop detail

The well known haricot bean variety in the area, *Awash Melka*, was sown on November 21, 2004 in and out of the lysimeters in all directions to have similar environment as in

normal fields and decrease advective effects. Before sowing, all the four lysimeters were made to have the same moisture content. The crop was harvested on March 7, 2005.

The row spacing and plant spacing were 40 cm and 10 cm respectively. Recommended doses of fertilizers of 100 kg/ha Urea and 100 kg/ha DAP were added to increase yield and obtain reasonable  $K_c$  value. Plant height was measured at each growth stage by taking representative 5 plants from each plot and measuring from the bottom at soil surface to the tip. Leaf area index (LAI) was monitored. The leaf area index (LAI) was determined as a ratio of leaf area per unit area of soil below it by taking representative 5 plants from each plot at different times during the growing season.

### 2.3 Measurement of soil moisture and irrigation application

Soil samples were collected at interval of 30 cm up to 90 cm depth for determination of some soil physical properties like field capacity, permanent wilting point, bulk density and texture. The average field capacity and permanent wilting points of the root zone profile were 31.6% and 15.0% respectively. The bulk density was 1.1 g/cm<sup>3</sup>. Neutron probe was used to monitor the soil moisture content. The probe was calibrated following standard procedure for neutron probe calibration by plotting the results of neutron probe reading and gravimetric sampling around the access tube. The moisture content was monitored at intervals of 30 cm up to 90 cm soil depth at different times during the growing season.

Irrigation water was applied to the crop when there was 30% depletion of the available soil moisture within the crop root zone (DOORENBOS and KASSAM, 1979). Similar irrigation amount at this depletion level was given to the crop in and out side the lysimeter to ensure uniform plant growth. The application of irrigation was carried out in known volume of buckets by converting the 30% depletion in terms of volume. Irrigation was terminated at crop maturity.

### 2.4 Determination of crop coefficient

Ideally,  $ET_o$  of the reference crop should be experimentally measured with a lysimeter. However, the alternative procedure is to determine  $ET_o$  from climatic data using the FAO Penman-Monteith method once the necessary variables specific to the location are determined. In this study,  $ET_o$  was calculated using FAO Penman-Monteith Equation (ALLEN et al. 1998) using weather data of the Melkassa weather station. The crop evapotranspiration for each growth stage of the crop was calculated by using water balance equation as:

$$ET_c = I + R - D + S \quad (1)$$

where  $ET_c$ : crop evapotranspiration (mm); I: irrigation (mm), R: rain fall (mm), D: drainage collected (mm), and S: decrease in storage of soil moisture (mm).

The crop coefficient value over a given period, such as decade, physiological growth stage or whole season, was then calculated as:

$$K_c = \frac{ET_c}{ET_o} \quad (2)$$

where  $K_c$ : crop coefficient;  $ET_c$ : crop evapotranspiration, and  $ET_o$ : reference crop evapotranspiration.

### 3 Results and Discussion

Crop evapotranspiration in 10 day intervals (decades) was calculated for each lysimeter using the water balance equation, Eq. (1). The result of the average of the four lysimeters is presented in Table 1. It can be observed from the Table that the peak water demand occurred almost three months after planting and only two weeks before harvest.

**Table 1:** Average potential crop evapotranspiration, reference crop evapotranspiration and crop coefficient values on 10-day interval basis.

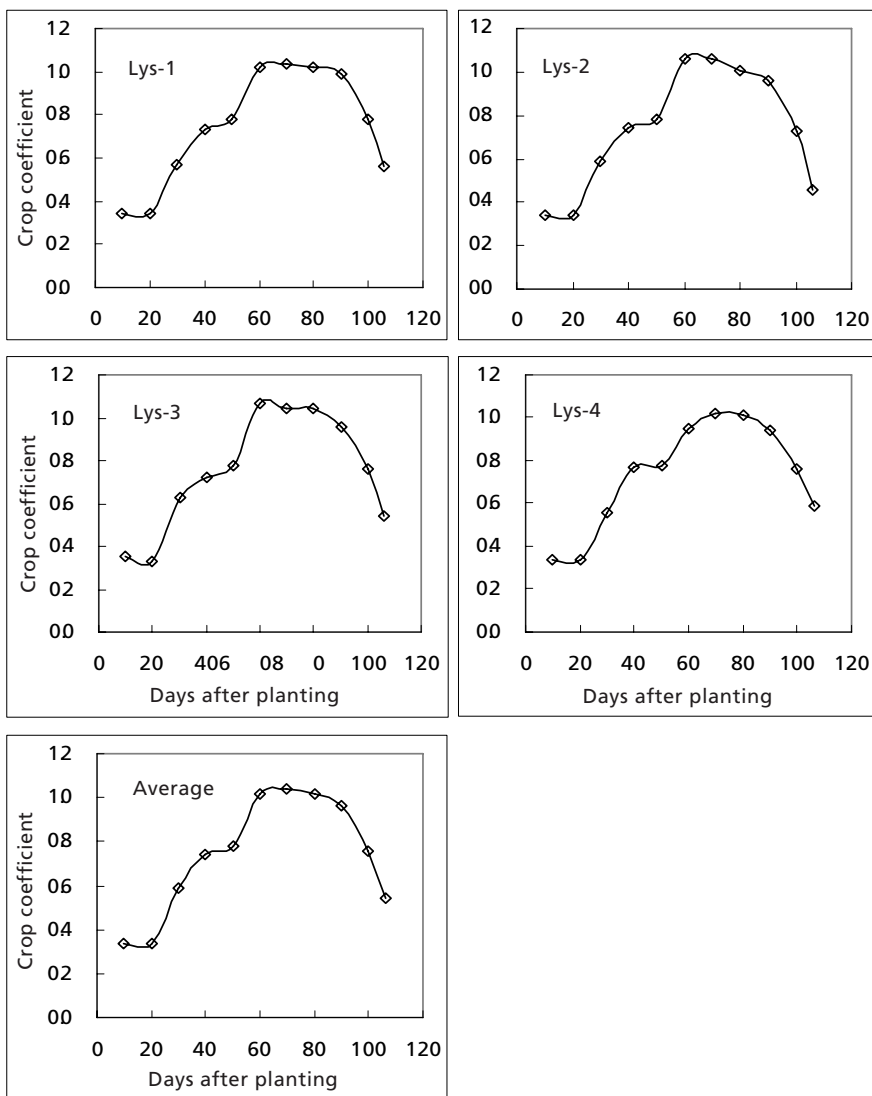
<i>Days after planting</i>	<i>Crop evapotranspiration <math>ET_c</math> (mm)</i>	<i>Reference evapotranspiration <math>ET_o</math> (mm)</i>	<i>Crop coefficient <math>K_c</math></i>
10	17.87	51.72	0.34
20	17.83	52.38	0.34
30	34.12	57.85	0.59
40	36.79	49.71	0.74
50	40.04	51.30	0.78
60	47.76	46.62	1.02
70	53.91	51.90	1.04
80	64.49	63.06	1.02
90	68.57	71.17	0.96
100	46.63	61.46	0.76
106*	19.15	35.37	0.54

\* row was calculated for 6 days period.

Crop coefficient values of haricot bean were obtained by dividing crop evapotranspiration measured by lysimeter with reference evapotranspiration, Eq. (2). Fig. 1 presents the seasonal evolution of crop coefficient values in each lysimeters calculated for decades (ten-day period). There is a general trend of  $K_c$  increment from initial stage to end of development stage and in the midseason stage the curves show almost constant values. As the results of water balance analysis showed no stress periods, the scatter of points can be assumed to be normal for an experimental data.

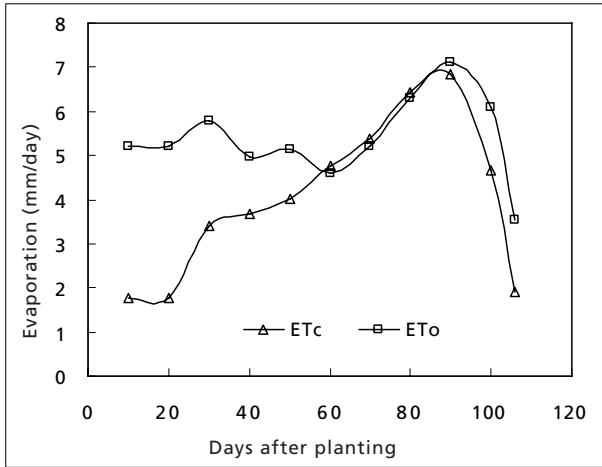
The evolution of  $K_c$  values reflected the effects of crop development and physiology on  $ET_c$ . Fig. 2. shows the general trend of  $ET_c$  and  $ET_o$  values of haricot bean calculated as average value of the four lysimeters.

**Figure 1:** Ten-day period  $K_c$  curves of haricot bean at Melkassa (Lys-1, Lys-2, Lys-3, and Lys-4 and refer to lysimeters 1, 2, 3, and 4 reservedly).



The observed growth stages of haricot bean at Melkassa were 20, 30, 40, and 16 days during initial, crop development, midseason and late season growth stages. The total growth cycle is 106 days. The values of crop coefficients calculated for each growth stage of haricot bean are presented in Table 2.

**Figure 2:** Average evapotranspiration values at Melkassa.



**Table 2:** Growth stage-wise  $K_c$  values of haricot bean at Melkassa.

	<i>Initial stage</i>	<i>Development stage</i>	<i>Mid season stage</i>	<i>Late season stage</i>
Duration (day)	20	30	40	16
$ET_c$ (mm)	35.61	110.96	234.74	65.78
$ET_o$ (mm)	104.10	158.86	232.75	96.83
$K_c$	0.34	0.70	1.01	0.68

The increase in  $K_c$  value from initial stage up to midseason stage is due to increase in ground cover of the crop, which has impact on evapotranspiration. During this stage, leaf area is small and evapotranspiration is mainly in the form of soil evaporation. This stage is terminated when 10% of the ground is covered (ALLEN *et al.*, 1998). As the crop develops and shades the ground to effective full cover and reach full size with increasing LAI, plant height and root depth, the amount of water abstraction increased which in turn increased the evapotranspiration. The evolution of  $ET_c$  indicated that maximum crop water requirement occurred at the end of the midseason stage, when evaporative demand was high. From the midseason stage to late season stage, there was a general decline in  $K_c$ . This decline is attributed to leaf senescence and to completion for assimilates between leaves and seed. Senescence is usually associated with less efficient stomatal conductance of leaf surfaces due to the effects of ageing, thereby restricting transpiration and causing a reduction in crop coefficient. Crop coefficient value at late season stage reflects crop and water management practices hence the crop at this stage need not get frequent irrigation as evaporation becomes restricted.



It can be observed that there is a slight variation in  $K_c$  values between the lysimeters observed during the crop development, midseason and late season stages. The computed overall average  $K_c$  values during initial, crop development; midseason and late season stages were 0.34, 0.70, 1.01 and 0.68 respectively.  $K_c$  value at the end of the growing season (harvest) was found to be 0.54. The  $K_c$  values for this crop given by WRIGHT (1982) at Kimberly, Idaho for initial, midseason and end of season stage were 0.15, 1.19 and 0.35. The  $K_c$  values suggested by ALLEN *et al.* (1998) for dry bean were 0.40, 1.15, and 0.35 for the initial, midseason and end of season. The differences of  $K_c$  values of the crop at different stages in different areas emphasize the need for local calibration of  $K_c$  values.

Some of the observed agronomic parameters (yield, LAI and plant height) of the crop are presented in Table 3. From the table, it can be observed that LAI and plant height increased as the crop passes through the different growth stages and reached maximum at the beginning of the midseason stage. Then after it decreased due to maturity of the crop associated with leaf ageing, senescence of leaves and leaf drop.

The recommended yield of this crop is 2500 kg/ha which is quite close to the observed average yield in this study. There is not as such significant difference in yield between the lysimeters indicating that the crop in each lysimeter has got the same amount of irrigation water at its depletion and the same amount of recommended doses of fertilizer.

**Table 3:** Agronomic parameters of haricot bean at Awash Melkassa.

<i>Experimental Lysimeter</i>	<i>Agronomic parameter</i>	<i>Initial stage</i>	<i>Development stage</i>	<i>Mid season stage</i>	<i>Late season stage</i>
Lys-1	Plant height (cm)	12.0	25.2	65.0	65.0
	LAI	0.70	2.00	3.50	1.50
	Yield (kg/ha)				2500.0
Lys-2	Plant height (cm)	12.20	25.8	65.5	66.0
	LAI	0.71	2.20	3.70	1.60
	Yield (kg/ha)				2520.0
Lys-3	Plant height (cm)	11.8	24.6	63.0	63.5
	LAI	0.70	2.10	3.40	1.30
	Yield (kg/ha)				2503.0
Lys-4	Plant height (cm)	12.2	25.5	64.0	64.0
	LAI	0.70	2.30	3.60	1.40
	Yield (kg/ha)				2510.0
Average	Plant height (cm)	12.1	25.4	64.4	64.6
	LAI	0.70	2.15	3.55	1.45
	Yield (kg/ha)				2508.3

## 4 Conclusion

From the study, it has been shown that estimates of crop water requirement made with locally determined crop coefficients slightly differ from estimates published in literature (e.g. ALLEN *et al.* (1998)). This emphasizes the strong need for local calibration of  $K_c$  for each variety. The fact that  $ET_c$  was measured locally makes the  $K_c$  values locally calibrated. Although the values may not be exactly the same as would be obtained with measured  $ET_o$ , they should be accurate enough for the purpose of estimating crop water requirements in the climatic region.  $ET_c$  and  $K_c$  are some what dependent on water management, i.e., operational criteria of irrigation system/method and amount of water supplied, variety, climate, location and other cultural differences. Thus, the  $K_c$  values obtained at in this study at Melkassa can be beneficial to areas with similar agroclimatic condition as that of Melkassa.

## References

- ALLEN, R. G., PEREIRA, L. S., RAES, D. and SMITH, M.; Crop Evapotranspiration; Guidelines for Computing Crop Water Requirements; FAO Irrigation and Drainage Paper No. 56. FAO, Rome, Italy;; 1998.
- BURMAN, R. D., NIXON, P. R., WRIGHT, J. L. and PRUITT, W. O.; Water requirements; in: *Design and Operation of Farm Irrigation Systems*, edited by JENSEN, M. E.; 189–232; Transaction of American Society of Agricultural Engineers, St. Joseph, Mich; 1980.
- DOORENBOS, J. and KASSAM, A. H.; Yield response to water; FAO Irrigation and Drainage Paper No. 33. FAO, Rome, Italy;; 1979.
- DOORENBOS, J. and PRUITT, W. O.; Guidelines for predicting crop water requirements; FAO Irrigation and Drainage Paper No. 24. FAO, Rome, Italy; 1977.
- IAR; Research on Haricot bean in Ethiopia; Institute for Agricultural Research, Ethiopia (IAR), Proceedings on a National Workshop, Addis Ababa; 1990.
- JENSEN, M., (Ed.) *Consumptive use of water and irrigation requirements*; Rep. Tech. Com. On Irrigation Water Requirements; Irrigation and Drainage Division, American Society of Civil Engineers; 1974; 227 pp.
- MARC; Progress Report for the period 1999/2000; Melkassa Agricultural Research Center (MARC), Ethiopia; 2001.
- PRUITT, W., LOURENCE, F. J. and VON OETTINGEN, S.; Water use by crops as affected by climate and plant factors; *Californian Agriculture*; 26(10):10–14; 1972.
- PRUITT, W. O., FERERES, E., KAITA, K. and SNYDER, R. L.; *Reference evapotranspiration ( $ET_0$ ) for "California"*; no. 1922 in *Agr. Exp. Sta. Bull.*; Univ. of California; 1987; 16 pp.
- TYAGI, N. K., SHARMA, D. K. and LUTHRA, S. K.; Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter; *Agricultural Water Management*; 45:41–54; 2000.
- WRIGHT, J. L.; New evapotranspiration crop coefficients; *Journal of Irrigation and Drainage Division, American Society of Civil Engineers*; 108(2):57–74; 1982.

## Influence of Cereal-Legume Rotation on *Striga* Control and Maize Grain Yield in Farmers' Fields in the Northern Guinea Savanna of Nigeria

I. Kureh<sup>\*1</sup>, A. Y. Kamara<sup>2</sup> and B. D. Tarfa<sup>1</sup>

### Abstract

On-farm trials were conducted in 2001, 2002, and 2003 in the northern Guinea savanna of Nigeria to evaluate integrated *Striga hermonthica* control measures under farmer-managed conditions. These included intercropping a *Striga*-resistant maize variety with cowpea for 3 years and also cropping this maize in rotation with legume trap crops - soybean and cowpea for 1-2 two years. Intercropping *Striga*-tolerant maize variety, Acr. 97TZL Comp. 1-W, with cowpea (*Vigna unguiculata* L.) consistently reduced *Striga* infestation in maize relative to continuously cropped sole maize over the three-year period. Maize grain yield was lower in the intercrop than in the sole maize plot probably due to competition from cowpea. However, because of the high value of cowpea in the intercrop, crop value for this system was higher than sole cropped maize. Legume-maize rotation reduced *Striga* infestation by 35% after one year of legumes in the rotation and by 76% after two years of legumes in the rotation. Soybean was more effective in reducing *Striga* infestation and also gave higher maize grain yield than cowpea. The rotation of these two legumes with maize had clear advantage over continuously cropped maize. Farmers should therefore be encouraged to adopt the introduction of grain legumes into the cereal cropping systems of the Nigerian savanna.

**Keywords:** maize, soybean, cowpea, cereal-legume rotation, intercropping, *Striga*

### 1 Introduction

The parasitic angiosperm, *Striga hermonthica* (Del.) Benth is an important weed mainly of C<sub>4</sub> cereals in the semi-arid tropics. Maize, sorghum, and millet are the most important hosts. The parasite can also infect upland rice. It has been estimated that about 40 to 70 million ha are severely or moderately infested in West African countries (LAGOKE *et al.*, 1991). Severe *Striga* infection can cause 70 - 80% crop loss in maize and sorghum and losses can be much higher under heavy infestations, even resulting in total crop failure (RICHES *et al.*, 1992; PARKER and RICHES, 1993). Farmers often have to abandon in-

---

\* corresponding author

<sup>1</sup> Department of Plant Science, Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), P.M.B. 1044, Zaria, Nigeria

<sup>2</sup> International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria; c/o L.W Lambourn & Co., Carolyn House, 26 Dingwall Road, Croydon CR93EE England

fested agricultural lands as a result of high soil infestation by *Striga* (KROSCHER, 1999). Recent trends away from traditional prolonged fallow and intercropping towards continuous cereal monocropping to meet the needs of increasing population have intensified the *Striga* problem. In addition to many factors already known, grazing cattle, crop seeds, and wind contribute to the spread of *Striga* infestation to new areas (BERNER *et al.*, 1996). The *Striga* problem is compounded by the plant's reproductive capacity. A single plant can produce over 50,000 seeds, which can remain viable in the soil for 15-20 years (MUSSELMAN, 1987; DOGGETT, 1988).

*Striga* research in Africa has a long history and a range of effective component control technologies has been identified (PARKER and RICHES, 1993). Examples of control options for *S. hermonthica* range from the use of leguminous trap-crops to stimulate suicidal germination of *Striga* seeds and therefore reduce the seed bank and improve soil fertility, to the use of resistant host-crop cultivars. SCHULZ *et al.* (2003) found that resistant maize following a soybean trap-crop yielded 1.58 t ha<sup>-1</sup> of grain and outyielded farmers' maize variety following traditional practices by more than 80%. The effectiveness of leguminous trap-crops in reducing the *Striga* seed bank was demonstrated by SAUERBORN (1999) in field experiments in Ghana where annual double cropping of trap-crops (soybean, sunflower and cotton) reduced the seed bank by about 30% each year. Similarly, SCHULZ *et al.* (2003) achieved 50% seed bank reduction after one year's rotation with soybean and cowpea under farmer-managed conditions. CARSKY *et al.* (2000) reported that *S. hermonthica* incidence in maize after soybean, compared to maize after sorghum, was significantly reduced from 3.2 to 1.3 emerged plants per maize plant, resulting in greatly improved grain yields.

In addition to host-plant resistance and legume trap-crops, a substantial amount of work has been carried out to study the effect of soil fertility on *Striga* infestation. Infestation is frequently associated with low soil fertility (CARSKY *et al.*, 2000; SCHULZ *et al.*, 2003). Hence, improved soil fertility conditions are likely to lead to reduced infestation (DEBRA *et al.*, 1998). The use of grain legumes can contribute to soil N (CARSKY and IWUAFOR, 1999). Estimates of fertilizer replacement values in a monomodal savanna zone of West Africa were 20 kg N ha<sup>-1</sup> from soybean and 45kg N ha<sup>-1</sup> from cowpea (KALEEM, 1993; CARSKY *et al.*, 1997). SANGINGA *et al.* (21001) reported that the grain yield of maize grown after soybean was increased by an average of 25% across two locations. They attributed this to enhanced N availability following soybean and other rotation effects, such as the reduction of soil-borne diseases. Intercropping, particularly of cereals with cowpea (*Vigna unguiculata*), is a common practice in many parts of the semi-arid zone. This is because food production is diversified, the risk of crop failure reduced, and resources for crop growth are utilized more efficiently compared to sole cropping (CARSKY *et al.*, 1994). Intercropping of cereals with legumes has also been proposed as a means of suppressing *Striga* in the cereal crop (VERNON, 1995; KUREH *et al.*, 2000). CARSON (1989) found that the density of emerged *Striga* plants, and soil temperature were both reduced when sorghum was associated with groundnut in Gambia.

Most *Striga*-infested areas already have high levels of the parasite seeds in the soil. The adoption of control measures that aim to reduce the level of this *Striga* seed inoculum has to be encouraged. The potentials of cereal-legume rotation and intercropping to manage *Striga* infestation in cereals has been demonstrated under controlled, researcher-managed conditions. It is therefore necessary to demonstrate that these technologies work efficiently under farmer-managed conditions and are indeed appropriate for African farmers (FISHER, 1999). The present study is a long-term farmer-managed *Striga* control project comparing short- and long-term rotation of a *Striga*-resistant maize with soybean and cowpea. Controls were maize intercropped with soybean and continuous cropping with *Striga*-resistant maize.

## 2 Materials and Methods

The trials were established with farmer management on 12 farmers' fields selected in two neighboring villages in Kaduna State, (northern Nigeria) in 2001, 2002, and 2003. The fields are located in the northern Guinea savanna zone, which is characterized by a sub-humid climate with monmodal rainfall of 900-1200mm, which extends over an annual growing period of 150-180 days. Rainfall was 1322 mm in 2001, 1007 mm 2002, and 1135 mm in 2003. The main characteristics of the soils are presented in Table 1.

**Table 1:** Soil properties in the trial sites.

<i>Property</i>	<i>Ungwan Shamaki</i>	<i>Tasha Kaya</i>
pH (CaCl <sub>2</sub> )	5.1	4.9
Total N (g kg <sup>-1</sup> )	0.2	0.08
Organic Carbon (g kg <sup>-1</sup> )	4.8	5.0
Bray 1-P (mg kg <sup>-1</sup> )	3.75	5.1

All trials were conducted on sites infested with *Striga hermonthica* and simultaneously served as demonstration plots for participating farmers. The treatments were as follows:

- (i) Cowpea-maize intercrop,
- (ii) one year of soybean followed by two years of maize,
- (iii) one year of cowpea followed by two years of maize,
- (iv) two years of soybean followed by one year of maize,
- (v) two years cowpea followed by one year of maize and
- (vi) continuous sole cropped maize as control.

The maize used was an improved *Striga*-tolerant open-pollinated maize variety (Acr. 97TZL Comp1-W). The soybean was an *Alectra*-tolerant and high N-fixing variety (TXG1448-2E) while the cowpea used in the intercrop was a *Striga*-tolerant early-maturing variety (IT93K452-1). The two legume varieties have been found to cause suicidal germination of *Striga* in screen house experiments (BERNER *et al.*, 1996). The experimental arrangement in each farmer's field is illustrated in Table 2.

**Table 2:** Arrangement of treatments on farmers' fields.

<i>Location</i>	<i>Year 1</i>	<i>Year 2</i>	<i>Year 3</i>
1	Resistant Maize	Resistant Maize	Resistant Maize
2	Soybean	Resistant Maize	Resistant Maize
3	Soybean	Soybean	Resistant Maize
4	Cowpea	Resistant Maize	Resistant Maize
5	Cowpea	Cowpea	Resistant Maize
6	Cowpea-maize intercrop	Cowpea-maize intercrop	Cowpea-maize intercrop

The trials were successfully established on eight farmers' fields at Ungwa Shamaki and four at Tashan Kaya. The villages were less than 5 km from each other and had similar soil and climatic conditions. Each farm with the six plots constituted a replicate. The gross plot size was 150m<sup>2</sup> and the net size was 135m<sup>2</sup>. In 2001, each crop was planted on ridges as a sole crop except for the maize-cowpea intercrop treatment. Maize was sown at 3 seeds per hill at a spacing of 75 × 50 cm. At two weeks after sowing (WAS), maize was thinned to two plants per stand. Soybean was drilled at a spacing of 5 cm on ridges with 75 cm interspace. In the sole cowpea variant, two seeds were planted on ridges at a spacing of × without thinning but in the intercrop variant one stand of cowpea was planted between two maize stands. In 2002 and 2003, the same operations were performed as in 2001.

All crops were hoe weeded at 3 and 6 WAS followed by a careful hand-pulling of other annual weeds except *Striga*.

Fertilizer was applied at the recommended rate of 100 kg N/ha, 50kg P/ha and 50kg K/ha using NPK and urea. The nitrogen fertilizer was split-applied at 3 and 6 WAS. Fertilizer was applied to soybean and cowpeas at the rate of 20kg N/ha, 40kg P/ha, and 20kg K/ha at 2 WAS using NPK (20:10:10), single superphosphate and muriate of potash. The cowpeas were sprayed with Cyper Plus (250 g Cypermethrin/ha) at the rate of 1 l/ha at flower bud initiation and Benlate (3 g Benomyl/ha) was applied at 0.4 kg/ha during podding to control fungal diseases and insect pests.

Data collected included maize stand count, *Striga* shoot count (infestation), number of maize plants infested (incidence), host damage severity on a scale of 1-9 (where 9 ≅ completely dead plants), and grain yield of maize, soybean and cowpea. Crop value in the systems was calculated using the Naira (₦, Nigerian currency) prices for the component commodity crops. The data were subjected to analysis of variance and treatment means were compared using Duncan Multiple Range Test (DMRT). Data on yield of soybean are not reported in this paper since they are not harvested from the same plot as maize.

**Table 3:** Effects of sole and intercropping on plant population, *Striga* infestation, crop damage severity and grain yield of maize on farmers' fields in northern Nigeria (2001).

Cropping system	Maize* (plants/ha)	Striga* (no./ha)	Infested maize* (plants/ha)	Crop damage <sup>†</sup> severity (1-9)	Maize grain yield (kg/ha)	Maize value (₦) <sup>‡</sup>	Cowpea seed yield (kg/ha)	Cowpea value (₦) <sup>§</sup>	Total value (₦)
Sole maize	21,013 <sup>a</sup>	1158.3 <sup>a</sup>	414.6 <sup>a</sup>	2.33 <sup>a</sup>	810.42 <sup>a</sup>	16,208	-	-	16,208
Maize-cowpea intercrop	17,371 <sup>b</sup>	433.3 <sup>b</sup>	295.8 <sup>b</sup>	2.58 <sup>b</sup>	613.54 <sup>a</sup>	12,270	306	9,180	21,450

\* at 12 WAS (weeks after sowing)

<sup>†</sup> Crop damage severity using a scale of 1 - 9, where 1 ≡ healthy plants and 9 ≡ completely dead plants

<sup>‡</sup> at ₦20/kg, <sup>§</sup> at ₦30/kg

**Table 4:** Effects of previous crops on plant population, *Striga* infestation, crop damage severity, and grain yield of maize on farmers' fields in northern Nigeria in the second year (2002).

Cropping system <sup>†</sup>	Maize* (plants/ha)	<i>Striga</i> * (no./ha)	Infested maize* (plants/ha)	Crop damage <sup>†</sup> severity (1-9)	Maize grain yield (kg/ha)	Maize value (₦) <sup>§</sup>	Cowpea seed yield (kg/ha)	Cowpea value (₦) <sup>¶</sup>	Total value (₦)
M-M	21,433 <sup>c</sup>	1191.7 <sup>a</sup>	343.8 <sup>a</sup>	4.08 <sup>a</sup>	1147.6 <sup>b</sup>	22,952	–	–	22,952
S-M	22,954 <sup>ab</sup>	772.9 <sup>b</sup>	272.9 <sup>b</sup>	3.50 <sup>b</sup>	1468.4 <sup>a</sup>	29,360	–	–	29,360
C-M	23,988 <sup>a</sup>	1025.0 <sup>ab</sup>	431.3 <sup>ab</sup>	3.67 <sup>b</sup>	1384.0 <sup>a</sup>	27,680	–	–	27,680
Maize-cowpea intercrop	22,513 <sup>bc</sup>	375.0 <sup>b</sup>	202.1 <sup>b</sup>	4.17 <sup>a</sup>	782.5 <sup>c</sup>	–	697	27,880	43,530

\* at 12 WAS (weeks after sowing)

† Crop damage severity using a scale of 1 - 9, where 1 ≡ healthy plants and 9 ≡ completely dead plants

‡ M-M ≡ sole maize, S-M ≡ maize after soybean, C-M ≡ maize after cowpea

§ at ₦20/kg, ¶ at ₦30/kg

Means followed by the same letter(s) within a column are not significantly different at 5% level of probability (DMRT).



**Table 5:** Effects of previous crops on plant population, *Striga* infestation, crop damage severity, and grain yield of maize on farmers' fields in northern Nigeria in the third year (2003).

Cropping system	Maize* (plants/ha)	<i>Striga</i> * (no./ha)	Infested maize* (plants/ha)	Crop damage† severity (1-9)	Maize grain yield (kg/ha)	Maize value (₦)‡	Cowpea seed yield (kg/ha)	Cowpea value (₦)§	Total value (₦)
M-M-M	23,022 <sup>b</sup>	489 <sup>a</sup>	273 <sup>a</sup>	4.5 <sup>b</sup>	1167 <sup>c</sup>	23,400	-	-	23,400
S-M-M	23,296 <sup>a</sup>	291 <sup>ab</sup>	173 <sup>ab</sup>	3.8 <sup>ab</sup>	1569 <sup>bc</sup>	31,380	-	-	31,380
C-M-M	23,216 <sup>a</sup>	293 <sup>ab</sup>	178 <sup>ab</sup>	4.1 <sup>a</sup>	1398 <sup>c</sup>	27,960	-	-	27,960
S-S-M	23,263 <sup>a</sup>	111 <sup>b</sup>	98 <sup>b</sup>	3.3 <sup>b</sup>	2185 <sup>a</sup>	43,700	-	-	43,700
C-C-M	23,076 <sup>b</sup>	121	<sup>b</sup> 86 <sup>b</sup>	3.7 <sup>ab</sup>	1939 <sup>ab</sup>	38,780	-	-	38,780
M-C intercrop	22,611 <sup>c</sup>	94 <sup>b</sup>	73 <sup>b</sup>	4.1 <sup>a</sup>	1400 <sup>c</sup>	28,000	680	27,200	55, 200

\* at 12 WAS (weeks after sowing)

† Crop damage severity using a scale of 1 - 9, where 1 ≡ healthy plants and 9 ≡ completely dead plants

‡ M-M-M ≡ maize-maize-maize, S-M-M ≡ soybean-maize-maize, C-M-M ≡ cowpea-maize-maize, S-S-M ≡ soybean-soybean-maize, C-C-M ≡ cowpea-cowpea-maize

§ at ₦20/kg, ¶ at ₦30/kg

Means followed by the same letter(s) within a column are not significantly different at 5% level of probability (DMRT).

### 3 Results

#### 3.1 Sole and intercropping effects on *Striga* and maize in the first year

In 2001, the sole-cropped and intercropped maize exhibited similar low levels of crop damage severity. The sole maize had better plant establishment than the intercropped maize although these were planted at the same density. *Striga* infestation and incidence were lower when maize was intercropped with cowpea than when planted sole. However, maize grain yield was 32% higher (not significant different at 5%) when planted sole compared to intercropped with cowpea (Table 3).

#### 3.2 Effects of one-year rotation on *Striga* infestation and maize grain yield

In 2002, plant population at harvest was generally lower than optimal for all treatments. Maize grown after one year of soybean and cowpea had a significantly higher plant population than the intercropped and continuously cropped maize. The number of emerged *Striga* was significantly higher in continuously cropped maize compared to maize after one year of soybean and cowpea intercropped maize (Table 4). *Striga* infestation was 70% lower in intercropped maize, 54% lower in maize after soybean, and 16% lower in maize after cowpea compared to continuously cropped maize. Crop damage severity was similar and higher in continuously cropped and intercropped maize than in maize after soybean and cowpea.

Maize after one year of soybean and maize after one year of cowpea had significantly higher grain yield than the intercropped and continuously cropped maize. Maize grain yield was 28% higher after one year of soybean and 21% higher after one year of cowpea than in the continuously cropped maize. Continuously cropped maize recorded 47% higher grain yield than the intercropped maize (Table 4). However, intercropping maize with cowpea produced 90% more crop value than sole cropped maize.

#### 3.3 Effects of two-year rotation on *Striga* infestation and maize grain yield

Plant population at harvest was generally lower than the recommended practice for all treatments in 2003 (Table 5). The number of emerged *Striga*/ha was significantly higher in continuously cropped maize than in maize grown after two years of soybean or cowpea and intercropped maize. *Striga* number was 81% lower in intercropped maize, 77% lower in maize after two years soybean, and 75% lower in maize after two years of cowpea than in continuously cropped maize. *Striga* number/ha in maize after two years of soybean was 62% lower than in maize after one year of soybean. *Striga* number/ha in maize after two years of cowpea was 59% lower than in maize after one year of cowpea. *Striga* number in maize continuously cropped for two years after one year of soybean or cowpea was 40% lower than in maize continuously cropped for three years without rotation with legumes. Continuously cropping the *Striga*-resistant/tolerant maize for three years reduced number of emerged *Striga*/ha by 57%. Crop damage severity in maize after two years of soybean was significantly lower than in all other treatments. Cropped damage severity in continuously cropped and intercropped maize increased with years of cultivation. However, crop damage scores were generally low for all treatments.

Maize grain yield after two years of soybean was 87% higher than maize continuously cropped for three years. Maize grain yield after two years of cowpea was 67% higher than the continuously cropped maize. Maize grain yield in maize-cowpea intercrop was 20% higher than the continuously cropped maize. Seed yield of cowpea in the intercropped was relatively lower than that normally obtained for sole crop of the cowpea variety used in this trial. Continuous cropping of maize for two years after one year of soybean and cowpea recorded grain yield 34 and 19% higher than maize continuously cropped for two years respectively. Maize grain yield after two years of soybean was 32.8% higher than maize grain yield after one year of soybean. Maize grain yield after two years of cowpea was 28.6% higher than maize after one year of cowpea. Intercropping maize with cowpea on the same plot for three years produced 136% more crop value than sole cropped maize.

### 3.4 Effects of previous crops on total soil nitrogen and available phosphorus

The effect of previous crops on total soil N at 0 to 10 cm depth is summarized in Table 6. Total N in the previous soybean and cowpea plots, and the intercropped maize plots was higher than in the continuously cropped maize plots. Mean total N in the plots previously cropped to legumes or intercropped with cowpea was 20% higher than the continuously cropped maize. There were no significant differences between previous soybean, cowpea, and maize-cowpea intercrops. Previous soybean and cowpea contributed similar amounts of N to the soil at all locations. Available P values in the soil were higher in plots previously cropped to soybean, cowpea or maize-cowpea intercropped than in continuously cropped maize. Average P values in plots after two years of soybean or cowpea were 70% higher than in continuously cropped maize. After one year of soybean or cowpea, average P values were 20% more than in continuously maize. P availability in maize-cowpea intercropped was not significantly different from two years of cowpea or soybean.

**Table 6:** Effect of previous crop on total soil nitrogen and available phosphorus before maize planting in 2003.

<i>Treatments</i>	<i>total N (g/kg)</i>	<i>avail. P (mg/kg)</i>
2 years sole maize	0.68	4.86
1 year soybean followed 1 year maize	0.79	4.99
2 years sole soybean	0.81	9.38
1 year cowpea followed by 1 year maize	0.81	6.91
2 years sole cowpea	0.83	7.18
2 years maize/cowpea intercrop	0.84	7.69
Mean	0.79	6.84
S.E.	0.02	0.79

## 4 Discussion

The trials demonstrated the potential of appropriate soybean and cowpea cultivars to reduce *Striga* parasitism in subsequent maize. It also demonstrated the potential of maize-cowpea intercrops to control *Striga*. The two legume cultivars used were able to reduce *Striga* parasitism in the rotation systems. Intercropping maize with cowpea reduced emerged *Striga* density. This reduction may be due to shading effects from the cowpea canopy. CARSON (1989) reported a positive relationship between soil temperatures under groundnut intercropped with sorghum and emerged *Striga* density. He found that the soil temperature at a depth of 10 cm at 6 to 7 weeks after sorghum emergence was about 2°C lower in sorghum rows and that *Striga* density at sorghum harvest was reduced by 60 to 70% in the treatment with sorghum and groundnut in the same row. CARSKY *et al.* (1994) reported that the number of mature capsule-bearing *Striga* plants was low when the cowpea ground cover was high in a sorghum-cowpea intercrop. This suggests that any spatial arrangement that increases cowpea ground cover at the base of maize or sorghum can reduce the density of mature *Striga*. CARSKY *et al.* (1994) therefore, concluded that in the long term, this might reduce the density of *Striga* seed, provided no importation of *Striga* seed to the field were allowed. They also found no significant reduction in sorghum yield by intercropping sorghum with cowpea. In the present study, intercropping cowpea with maize reduced maize yield by 47% despite the reduction in the number of emerged *Striga*. This may be due to a competition effect from the cowpea crop on the maize crop. This corroborates the findings of KUREH *et al.* (2000) and KUCHINDA *et al.* (2003). When maize and cowpea are planted at the same time in intercropping systems, the fast growing and profuse branching cowpea competes with the maize crop for light, water, and nutrients. This slows than maize growth considerably thereby reducing yield. Maize and sorghum appear to have different reactions to competition effects from other crops in intercropping systems. Maize has a shorter maturity period than sorghum. Hence, sorghum may overcome the effects of intercropping long after the cowpea has been harvested. Intercropping maize with cowpea is a good agronomic practice for *Striga* management due to reduced *Striga* infestation and high total crop value. KUREH *et al.* (2000) similarly reported better *Striga* management and increased crop value when soybean is intercropped with maize.

Despite the considerable reduction in maize yield when intercropped with cowpea, this system recorded higher crop value than the sole cropped maize in both rotation with legumes or when continuously cropped. Grain yield reduction of maize when intercropped with cowpea was compensated for by the higher cash value of cowpea in the intercropping system. Because of this reason, intercropping may continue to be one of the options for *Striga* control.

Several studies have shown a significant reduction in *Striga* attack by adopting cropping systems that include intercropping and rotations (CARSKY *et al.*, 1994, 2000; SCHULZ *et al.*, 2003; KUCHINDA *et al.*, 2003). Several other mechanisms can be suggested to explain the reduction of *Striga* when maize is intercropped or rotated with legume trap crops. In addition to shading out *Striga* in intercropping systems, the cowpea or soybean has been shown to stimulate the germination of *Striga* without acting as hosts

(CARSKY *et al.*, 1994; BERNER *et al.*, 1996; CARSKY *et al.*, 2000; KUREH *et al.*, 2000; KUCHINDA *et al.*, 2003). In this study, the extent of reduction in *Striga* infestation was dependent on the type of legume and number of years soybean or cowpea were cultivated before maize cultivation. For example, *Striga* infestation was 54% lower after one year of soybean and 16% lower after one year of cowpea. However, in the second year, there was higher level of reductions when the legumes were cultivated for two years before maize was cultivated. *Striga* infestation in maize was reduced by 77% after two years of soybean and 75% after two years of cowpea. In addition, maize grain yield increased by 87% after two years of soybean and 66% after two years of cowpea. These indicate the ability of these grain legumes to reduce *Striga* infestation and increase grain yield. On heavily infested *Striga* fields, more frequent cultivation of grain legumes before the introduction of cereals may be necessary.

*Striga* germination may also be suppressed by the nitrogen fixed by the legumes. However, this does not appear to be likely because the legumes do not release much nitrogen into the soil during their growth (VAN DER HEIDE *et al.*, 1985; CARSKY *et al.*, 1994; SANGINGA *et al.*, 2002). Usually large amounts of nitrogen are required to reduce *Striga* density (MUMERA and BELOW, 1993). However, improved growth and vigor due to N may help the maize crop to overcome *Striga* attacks. Although there were significant reductions in *Striga* infestation and maize yield loss due to *Striga*, *Striga* infestation and damage ratings in the continuously cropped maize was lower than that reported for *Striga*-susceptible maize in the savanna (A. MENKIR, personal communication). This is because the maize variety used was *Striga*-resistant/tolerant. It is presently the most resistant maize against *Striga* in the West African savanna. Its continuous cultivation may lead to reduction in the *Striga* seed bank.

Although the above benefits of legume rotation in *Striga* control may be unrelated to N supply, our data show that legume-maize rotation increased N supply to subsequent maize. Although all treatments received equal amounts of fertilizer N (100 kg N/ha), total N in previous legume plots was more than in continuous maize plots. This additional N supply coupled with other rotational effects may have increased the yield of subsequent maize. CARSKY *et al.* (1997) established N supply as the major influence of soybean on subsequent maize and found a reduction in maize yield response to inorganic N following soybean. The increases in N supply in previous cowpea and soybean treatments and yield of subsequent maize was probably due to additional N fixed and left in the soil for the subsequent maize crop. SANGINGA *et al.* (2002) reported a nodulating soybean to fix about 103 kg N/ha of its total N with an estimated net N balance input from fixation following grain harvest of 43 kg N/ha. They also reported that maize growing after this soybean had 1.2 to 2.3-fold increase in yield compared to the maize control. In the present study, N contents of roots and litter of the previous soybean and maize crops were not determined, so the two effects could not be quantified.

## 5 Conclusion

It can be concluded from our findings that:

- (1) Continuous cultivation of sole maize will increase *Striga* infestation. However, if the maize grown is resistant to *Striga*, there may be some reduction in field infestation due to depletion of *Striga* seed bank.
- (2) Rotation of cereals and grain legumes such as soybean and cowpea can reduce *Striga* infestation and increase grain yield. The reduction of *Striga* infestation and maize yield increases will be higher if the legumes are cultivated for over one cropping seasons before maize is introduced.
- (3) Although, maize-cowpea intercropping reduced maize grain yield due to competition effects, the higher crop value of cowpea component makes the system profitable and farmers should be encouraged to continue practicing it.

## Acknowledgements

The authors thank the Cereal Programme staff of IAR/ABU for technical support and West African Maize Network (WECAMAN) for Research Grant.

## References

- BERNER, D. K., CARSKY, R. J., DASHIELL, K., KLING, J. and MANYONG, M.; A land management based approach to integrated *Striga hermonthica* management in Africa; *Outlook on Agric.*; 25:157–164; 1996.
- CARSKY, R., BERNER, D. K., OYEWOLE, B. D., DASHIELL, K. and SCHULZ, S.; Reduction of *Striga hermonthica* parasitism on maize using soybean rotation; *Internat. J. Pest Manage.*; 46(2):115–120; 2000.
- CARSKY, R. J., ABAlIDO, R., DASHIELL, K. and SANGINGA, N.; Effect of soybean on subsequent grain yield in the Guinea savanna zone of West Africa; *Afri. Crop Sci.*; 1:33–38; 1997.
- CARSKY, R. J. and IWUAFOR, E. N. O.; Contribution of soil fertility research and maintenance to improved maize production and productivity in sub-Saharan Africa; in: *Strategy for sustainable maize production in West and Central Africa. Proceedings of a Regional Maize Workshop*, edited by BADU-APRAKU, B., FAKOREDE, M. A. B., OUEDRAGGO, M. and QUIN, F. M.; IITA-Cotonou, Benin Republic, 21-25 April, 1997. WECAMAN/IITA, Nigeria; 1999.
- CARSKY, R. J., SINGH, L. and NDIKAWA, T.; Suppression of *Striga hermonthica* on sorghum using cowpea intercrop; *Expt. Agric.*; 30:349–358; 1994.
- CARSON, A. G.; Effect of intercropping sorghum and groundnuts on density of *Striga hermonthica* in the Gambia; *Tropical Pest Manage.*; 35:130–132; 1989.
- DEBRA, S. K., DEFOER, T. and BENGALY, M.; Integrating farmers' knowledge, attitude and practice in the development of sustainable *Striga* control interventions in southern Mali; *Netherlands J. of Agric. Sci.*; 46:65–75; 1998.

- DOGGETT, H.; Witch weeds (Striga); in: *Sorghum, 2nd edition*, edited by WRIGLEY, G.; 368–404; Longman Scientific and Technical, London, UK; 1988.
- FISHER, P. A.; *Action research in extension material and message development: The Striga problem of northern Ghana revisited*; Margraf Verlag, Weikersheim, Germany; 1999.
- VAN DER HEIDE, J., VAN DER KRUIJS, A. C. B. M., KANG, B. T. and VLEK, P. L.; Nitrogen management in multiple cropping systems; in: *Nitrogen Management in Farming Systems in Humid and Sub humid Tropics*, edited by KANG, B. T. and VAN DER HEIDE, J.; 291–306; Haren: Institute for Soil Fertility (IB); 1985.
- KALEEM, F. Z.; Assessment of N benefit from legumes to following maize crop; in: *1989 Annual Report of Nyankpala Agricultural Experimental Station. Tamale, Ghana*; 109–133; GTZ, Eschborn, Germany; 1993.
- KROSCHER, J.; Analysis of the Striga problem, the first step towards joint action; in: *Advances in Parasitic weed control at on-farm level*, edited by KROSCHER, J., MERCER-QUARSHIE, H. and SAUERBORN, J.; vol. 1; 3–26; Margraf Verlag, Weikersheim, Germany; 1999.
- KUCHINDA, N. C., KUREH, I., TARFA, B. D., SHINGU, C. and OMOLEHIN, R.; On-farm evaluation of improved maize varieties intercropped with some legumes in the control of Striga in the northern Guinea Savanna of Nigeria; *Crop Prot.*; 22:533–538; 2003.
- KUREH, I., CHIEZEY, U. F. and TARFA, B. D.; On-station verification of the use of soybean trap crop for the control of Striga in maize; *Afri. Crop Sci. J.*; 8:295–300; 2000.
- LAGOKE, S. T. O., PARKINSON, V. and AGUNBIADE, R. M.; Parasitic weeds and their control methods in Africa; in: *Combating Striga in Africa*, edited by KIM, S. K.; 3–14; International Institute of Tropical Agriculture, Ibadan, Nigeria; 1991.
- MUMERA, L. M. and BELOW, F. E.; Role of nitrogen in resistance to Striga parasitism of maize; *Crop Sci.*; 33:758–763; 1993.
- MUSSELMAN, L. J.; *Parasitic Weeds in agriculture*; vol. 1; CRC press, Boca Raton, FL; 1987.
- PARKER, C. and RICHES, C. R.; *Parasitic Weeds of the World: Biology and Control*; chap. Striga, the witchweeds, on cereal crops, 1–74; CAB International. Wallingford, Oxon OX10 8DE, United Kingdom; 1993.
- RICHES, C. R., HAMILTON, K. A. and PARKER, C.; Parasitism of grain legumes by *Alectra* species (Scrophulariaceae); *Ann. Appl. Biol.*; 121:361–370; 1992.
- SANGINGA, N., OKOGUN, J. A., VANLAUWE, B. and DASHIELL, K.; The contribution of nitrogen by promiscuous soybeans to maize based cropping system in the moist savanna of Nigeria; *Plant and Soil*; 241:223–231; 2002.
- SANGINGA, N., OKOGUN, J. A., VANLAUWE, B., J., D., CARSKY, R. J. and DASHIELL, K.; Nitrogen contribution of promiscuous soybeans in maize-based cropping systems; in: *Sustaining Soil Fertility in West Africa*, edited by TIAN, G., ISHIDA, F. and KEATING, D.; SSSA Special Publication no. 58, Soil Science Society of America and American Society of Agronomy, Madison, WI 53711, USA.; 21001.

- SAUERBORN, J.; *Striga* biology versus control; in: *Advances in Parasitic weed control at on-farm level, Vol. 1: Joint action to control Striga in Africa*, edited by KROSCHER, J., MERCER-QUARSHIE, H. and SAUERBORN, J.; 133–144; Margraf Verlag, Weikersheim, Germany; 1999.
- SCHULZ, S., HUSSAINI, M. A., KLING, J. G., BERNER, D. K. and IKIE, F. O.; Evaluation of integrated *Striga hermonthica* control technologies under farmer management; *Expt. Agric.*; 39:99–108; 2003.
- VERNON, K. H.; Trap-cropping, intercropping and manual removal show promise on *Striga asiatica* control in maize in Malawi; The 3rd Regional *Striga* Working Group Meeting. Mombasa. (Kenya) Tanga (Tanzania). June 12-14; pp. 12-15; 1995.



## Wirkungen eines polymeren Bodenverbessers auf die Ertragsbildung von Hirse unter ariden Bedingungen

S. Banedjschafie<sup>\*1</sup> und H. Herzog<sup>2</sup>

### Zusammenfassung

Wasser ist in (semi)ariden Gebieten der entscheidende begrenzende Faktor in der Pflanzenproduktion. Unter dem Aspekt einer erhöhten Wasserspeicherung wurde die Wirkung einer Polymer-Gabe von 0 bzw. 0.3 % (G/G) zu drei Böden (leicht/mittel/schwer) bei drei Bewässerungsfrequenzen (4-, 8-, und 12-tägig) auf die Ertragsbildung von Hirse (*Panicum antidotale* Retz), die Wasserspeicherung und N-Auswaschung im Freiland (nordwestlich von Teheran) geprüft.

Vierzig Tage (d) nach Versuchsbeginn sank die Überlebensrate der Pflanzen, insbesondere auf leichtem Boden und bei geringer Bewässerungsfrequenz progressiv. Polymer-Zusatz und eine erhöhte Bewässerungsfrequenz zeitigten bei allen Pflanzenmerkmalen klare positive Wirkungen, wobei z. T. deutliche Interaktionen, auch mit den Böden bestanden. Auf allen Böden, insbesondere aber auf mittlerem Boden, welcher die Rispen- und Biomassebildung begünstigte, war der Effekt des Polymerzusatzes bei geringer bzw. mittlerer Bewässerungsfrequenz am stärksten ausgeprägt. Die Wechselwirkungen zwischen den Versuchsfaktoren werden vor dem Hintergrund einer durch Polymerzusatz erhöhten Wasserspeicherung und verminderten N-Auswaschung diskutiert.

**Stichwörter:** Polymer, Wasserspeicherung, Bewässerungsfrequenz, Bodenarten, Ertragsbildung von Hirse, Überlebensrate, N-Auswaschung

### 1 Einleitung

Wasser stellt ein Hauptproblemfaktor in der Pflanzenproduktion arider und semiarider Regionen dar. Nicht nur die natürliche Wasserknappheit begrenzt die Standortproduktivität, sondern auch ungünstige physikalische Bodeneigenschaften, wie geringe Infiltration, sowie Wasserspeicherung und -nachlieferung. Neben der Anwendung von Gründüngung, Mulchen oder anderer organischer Dünger, die zur Milderung dieser Probleme beitragen können, ist in den letzten Jahren auch der Einsatz von polymeren Bodenverbessern getestet worden. Hierzu zählen z.B. Perlit, Igeta, Hydroplus und andere Superabsorbenten bzw. Polymere. Diese Mittel können bei Kontakt mit Was-

---

\* corresponding author

<sup>1</sup> Schahram Banedjschafie, Research Institute of Forests & Rangelands, Desert Division, P.O. Box 13185-116 Teheran/Iran, E-Mail: sbjschafie@rifr-ac.ir

<sup>2</sup> Prof. Dr. agr. Helmut Herzog, Institut für Pflanzenbauwissenschaften, Humboldt-Universität zu Berlin, Albrecht-Thaer-Weg 5, D-14195 Berlin

ser das 300 bis 500-fache ihres Volumens an Wasser absorbieren und es wieder an die Pflanzen abgeben. Neben dieser Wasserabsorption, die zu einer besseren Pflanzen- und Wurzelentwicklung führen kann, ist auch eine verminderte Nährstoffauswaschung aus dem Boden durch Polymere zu erwarten, wobei die Wirksamkeit im Boden mit bis ca. 5 Jahren angegeben wird (*Super AB, A-100*, Iran Polymer Institute). Polymere Bodenverbesserer können bei Neuanpflanzungen von Baumkulturen auf leichteren Böden trockener Klimata positive Effekte erzielen, wie Dosiseffekte von Polymerzusätzen zum Boden auf die Überlebensrate von Kiefern Sämlingen (*Pinus halepensis*) in Versuchen von HÜTTERMANN *et al.* (1997) belegen. In Versuchen mit *Populus euphratica* auf salzhaltigem Boden (Hüttermann *et al.* 1997) liessen Polymer-Behandlungen mit 0 % bis 0.6 % nach 7 und nach 60 Tagen ebenfalls abgestufte, deutliche Verbesserungen von Wachstum und Überlebensrate erkennen.

Aus anderen Bewässerungsversuchen von HÜTTERMANN *et al.* (1999) auf leichten Wüstenböden geht hervor, dass die durch Polymere gesteigerte Wasserspeicherung einen entscheidenden Einfluss auf das Überleben der Pflanzen ausübten. Darüber hinaus konnte in diesen Versuchen, wie auch in denen von DEHGAN *et al.* (1994), eine erhöhte Wurzelmasse bei Polymerzugaben beobachtet werden. In einem weiteren Bericht über Polymerversuche in Südafrika wird mitgeteilt, dass durch die Verwendung von Polymeren im Boden nicht nur die Sterblichkeitsrate von Eukalyptuspflanzen deutlich reduziert wurde, sondern auch die Bewässerungskosten abnahmen (ANONYMOUS, 1998).

Ziel dieser Untersuchung war es, zu prüfen, inwieweit auch an annualen Nutzpflanzen unter den ariden Bedingungen des Irans positive Wirkungen von Polymerzugaben nachgewiesen werden können. Darüber hinaus sollten mögliche Wechselwirkungen mit Bewässerungsmassnahmen bzw. mit unterschiedlichen Wasserspeicherkapazitäten von Böden untersucht werden. Als annuelle Pflanze wurde hier Futterhirse (*Panicum antidotale* Retz.) ausgewählt, weil diese Pflanze neben Viehfutter auch als Schutz gegen Winderosionen in Trocken- bzw. Wüstengebieten eingesetzt werden kann.

## 2 Material und Methoden

Die Untersuchungen wurden in einem Gefässversuch im Freiland während des Jahres 2000 am Forschungsinstitut für Wald und Weidewirtschaft (16 km nord-östlich von Teheran, 1300 m ü. NN) durchgeführt. Die mittleren jährlichen Niederschläge betragen dort ca. 230 mm mit Schwerpunkten im Frühjahr und im Spätherbst, so dass während der Versuchsmonate im Sommer weniger als 10 mm Regen fielen. Während des Versuchszeitraums betrug die monatliche Verdunstung ca. 170 mm und die mittleren Temperaturen lagen bei 21°C. Das Saatgut der Futterhirse (*Panicum antidotale* Retz.) wurde aus der Genbank des Forschungsinstituts (für Wald- und Weidewirtschaft) bezogen und zuvor auf seine Keimfähigkeit geprüft. Es wurden vier Körner pro Gefäss ausgesät und später auf eine Pflanze pro Topf ausgedünnt. Die Gefässe wurden jeweils mit 4 kg Boden unterschiedlicher Herkunft und Art (leicht, mittel und schwer, s. Tab. 1) befüllt. Den Böden wurde eine Dosis von 0 bzw. 0,3 % (G/G) des Polymers *Super AB, A-100* (Iran Polymer Institute) zugesetzt, welches den Verhältnissen in anderen Untersuchungen entsprach (WANG und GREGG, 1990; BOWMAN *et al.*, 1990; DEHGAN *et al.*, 1994; HÜTTER-

MANN *et al.*, 1997, 1999). Das verwendete Polymer bestand aus Polyacrylsäure mit einer Körnung von 0,05 - 0,15 mm, einer Dichte von 1,4 - 1,5 g/cm<sup>3</sup> und hatte einen pH-Wert von 6 - 7 im wassergesättigten Zustand, welcher bei 203 g/g Polymer erreicht war. Die Bewässerung wurde mit 3 unterschiedlichen Frequenzen, alle 4, 8 oder 12 Tage vorgenommen, wobei zu jedem Bewässerungstermin den Gefässen entsprechend des Gewichts Wasser bis zum leichten Überschreiten der Feldkapazität zugegeben wurde.

Der Versuch war als split-split-plot design angelegt mit 3 Bewässerungsfrequenzen (3 main plots), die jeweils die 3 Bodenarten (3 split plots) beinhalteten, die wiederum jeweils in den unbehandelten und polymer-behandelten Boden (2 subsplit plots) unterteilt waren. Der Versuch wurde mit 4 Wiederholungen durchgeführt.

Die Düngermengen für N-P-K entsprachen den Empfehlungen von FINCK (1992) (berechnet über 80 000 Pflanzen/ha). Eine P- und K-Düngung (35 kg P/ha, 200 kg K/ha) wurde in Form von Triplesuperphosphat und Kaliumsulfat vorgenommen und dem Boden vor der Saat beigemischt. Die Stickstoffdüngung wurde mit ca. 100 kg/ha N dem Boden als wässrige Lösung in Form von Ammoniumnitrat zugeführt. Ein Viertel der N-Menge wurde im Sämlingsstadium, der Rest zur Blüte verabreicht. Die jeweils nach der N-Applikation erfolgenden 2 Bewässerungen waren derart bemessen, dass jeweils ca. 50-80 ml Sickerung erzeugt wurde, um den Einfluss des Bodenverbessers auf die potentielle N-Auswaschung ermitteln zu können.

Die Bodenkennwerte (Tab. 1) wurden im Labor des Research Institute of Forest & Rangelands i. W. nach Standardmethoden ermittelt (elektrische Leitfähigkeit und pH-Wert im Sättigungs-extrakt elektrometrisch, Stickstoff nach Kjeldahl mit Aufschluss nach ROWELL (1994), Carbonatgehalt nach SCHLICHTING *et al.* (1995), Phosphat nach Olsen gemäß SCHINNER *et al.* (1991), Kalium mit 1N Ammoniumacetat nach COTTENIE (1980), organischer Kohlenstoff nach Walkley und Black gemäß BARUAH und BARTHAKUR (1997), KAK mit Ammonium bzw. Natrium flammenphotometrisch und Korngrößenverteilung hydrometrisch).

**Tabelle 1:** Kenndaten der unbehandelten Versuchsböden.

Bodenart (% Ton/Schluff/Sand)	pH	EC [dS m <sup>-1</sup> ]	P [mg kg <sup>-1</sup> ]	K [cmol kg <sup>-1</sup> ]	KAK [%]	WGS* [%]	N <sub>t</sub> [%]	OC [%]	CaCO <sub>3</sub> [%]
leicht (2/2/96)	7.42	1.65	0.10	5.7	4.1	26.7	0.029	0.21	5.33
mittel (20/50/30)	7.78	3.51	0.25	27.1	8.2	35.9	0.045	0.40	6.67
schwer (30/38/32)	7.33	2.23	0.14	12.8	8.7	40.4	0.056	0.51	9.33

\* Wassergehalt bei Sättigung [% G/G], ermittelt aus Gewicht im gesättigten und stark luftgetrockneten Boden.

An den Pflanzen wurde die phänologische Entwicklung (Feldaufgang, Schoss- und Blühbeginn, absolute Pflanzenanzahlen) jeweils an verschiedenen Tagen bonitiert und später die Überlebensrate regelmässig erfasst. Zur Varianzanalyse der Überlebensrate wurden die Daten zunächst nach der Formel  $X = \sqrt{x + 0.5}$  transformiert und anschliessend analysiert, wobei  $x$  den Wert 0 für abgestorbene und 1 für lebende Pflanzen annehmen

konnte. Bei der Probenahme einzelner Pflanzen wurde die Trockenmasse (105°C), die Rispenanzahl und die Pflanzenhöhe ermittelt. Das Datenmaterial wurde einer Varianzanalyse unterzogen und bei Vorliegen von signifikanten Effekten wurden Mittelwertvergleiche mittels des Duncan-Tests durchgeführt. Die Auswertung erfolgte mit dem Statistikprogramm MSTAT.

### 3 Ergebnisse

Die phänologische Entwicklung der Futterhirse war gekennzeichnet durch Aufgang am 7.-9. Tag nach der Saat (TnS), Schossbeginn zwischen dem 31.-38. TnS und Blühbeginn zwischen dem 52.-55. TnS. Die drei Versuchsfaktoren zeitigten bei allen fünf Pflanzenmerkmalen (Tab. 2) signifikante Hauptwirkungen, aber auch Wechselwirkungen, insbesondere zwischen der Bewässerung (A) und dem Boden (B). Bezüglich der Hauptwirkungen (Tab. 3) erwies sich der mittlere Boden generell als das günstigste Substrat und eine Verringerung der Bewässerungsfrequenz senkte sowohl Überlebensrate, die Pflanzenhöhe, Rispenanzahl und Trockenmasse der Hirse stufenweise; hierbei war die Reduktion jeweils auf dem leichten Boden relativ am stärksten ausgeprägt. Ein positiver Effekt des polymeren Bodenverbessers auf die Überlebensrate der Hirse (Abb. 1) prägte sich zunehmend ab dem 35 TnS aus, und erhöhte die Rate zur Reife absolut um 10 %, was im wesentlichen auf der Wirkung bei leichtem Boden mit 4- und 8-tägiger Bewässerung und bei mittlerem Boden bei 12-tägiger Bewässerung beruhte (vergl. Tab. 3).

**Tabelle 2:** Varianzanalysen zum Einfluss der Versuchsfaktoren Bewässerung (A), Boden (B) und Polymerzusatz (C) auf verschiedene Merkmale.

Quelle	F-Werte					
	Freiheitsgrade	Überlebensrate <sup>†</sup>	Rispenzahl	Pflanzenhöhe	Trockenmasse	N im Dränwasser
A	2 (1) <sup>‡</sup>	10.5**	18.3***	13.8***	47.6**	32.8**
B	2	33.4**	72.7***	37.1***	75.1**	14.3**
AB	4	7.0**	5.8**	1.4 <sup>n.s.</sup>	4.9**	5.9*
Error	27 (6) <sup>‡</sup>	–	–	–	–	–
C	1	4.8*	15.1***	13.1**	67.3**	10.2*
AC	2	0.3 <sup>n.s.</sup>	0.6 <sup>n.s.</sup>	0.01 <sup>n.s.</sup>	0.5 <sup>n.s.</sup>	0.6 <sup>n.s.</sup>
BC	2	2.1 <sup>n.s.</sup>	1.6 <sup>n.s.</sup>	1.0 <sup>n.s.</sup>	3.5*	0.9 <sup>n.s.</sup>
ABC	4	1.7 <sup>n.s.</sup>	4.4**	3.6*	3.3*	0.1 <sup>n.s.</sup>
Error	27 (6) <sup>‡</sup>	–	–	–	–	–
Total	71 (23) <sup>‡</sup>	–	–	–	–	–

<sup>†</sup> Freiheitsgrade ( ) für N im Dränwasser; <sup>‡</sup> transformierte Daten

\* / \*\* : signifikant bei p = 0.05 bzw. 0.01, <sup>n.s.</sup> : not significant

Das Zusammenwirken der drei Versuchsfaktoren auf die wichtigen Ertragsmerkmale Rispenanzahl und Trockenmasse (Abb. 2 und 3) war sehr ähnlich, wobei ein positiver Polymer-Effekt sich praktisch auf allen Boden×Bewässerung-Kombinationen abzeichne-

**Tabelle 3:** Haupt- und Wechselwirkungen<sup>1</sup> von Bewässerung (A) und Boden (B) auf die diversen Merkmale der Rispenhirse am Versuchsende.

Merkmal	Boden	Bewässerungsfrequenz			Boden (B)
		4-tätig	8-tätig	12-tätig	
Überlebensrate [%] <sup>2</sup>	leicht	88.8 <sup>a</sup>	55.0 <sup>b</sup>	10.0 <sup>c</sup>	51.3 <sup>β</sup>
	mittel	100.0 <sup>a</sup>	100.0 <sup>a</sup>	88.8 <sup>a</sup>	96.3 <sup>α</sup>
	schwer	100.0 <sup>a</sup>	100.0 <sup>a</sup>	100.0 <sup>a</sup>	100.0 <sup>α</sup>
	Bewässerung (A)	96.3 <sup>α</sup>	85.0 <sup>α</sup>	66.3 <sup>β</sup>	–
Pflanzenhöhe [cm]	leicht	Keine signifikante Wechselwirkung ( <i>n.s.</i> ) zwischen A×B			17.2 <sup>β</sup>
	mittel				46.6 <sup>α</sup>
	schwer				54.3 <sup>α</sup>
	Bewässerung (A)	52.5 <sup>α</sup>	36.7 <sup>β</sup>	29.0 <sup>β</sup>	–
Rispenanzahl je Pflanze	leicht	1.1 <sup>d</sup>	0.3 <sup>e</sup>	0.0 <sup>e</sup>	0.5 <sup>γ</sup>
	mittel	9.3 <sup>a</sup>	5.4 <sup>b</sup>	3.3 <sup>c</sup>	6.0 <sup>α</sup>
	schwer	2.6 <sup>cd</sup>	1.4 <sup>cde</sup>	1.4 <sup>cde</sup>	1.8 <sup>β</sup>
	Bewässerung (A)	4.3 <sup>α</sup>	2.4 <sup>β</sup>	1.6 <sup>β</sup>	–
Trockenmasse je Pflanze [g]	leicht	2.20 <sup>d</sup>	0.68 <sup>e</sup>	0.00 <sup>e</sup>	0.96 <sup>γ</sup>
	mittel	6.75 <sup>a</sup>	3.74 <sup>b</sup>	2.53 <sup>cd</sup>	4.34 <sup>α</sup>
	schwer	3.48 <sup>bc</sup>	2.35 <sup>d</sup>	2.09 <sup>d</sup>	2.64 <sup>β</sup>
	Bewässerung (A)	4.14 <sup>α</sup>	2.25 <sup>β</sup>	1.54 <sup>γ</sup>	–

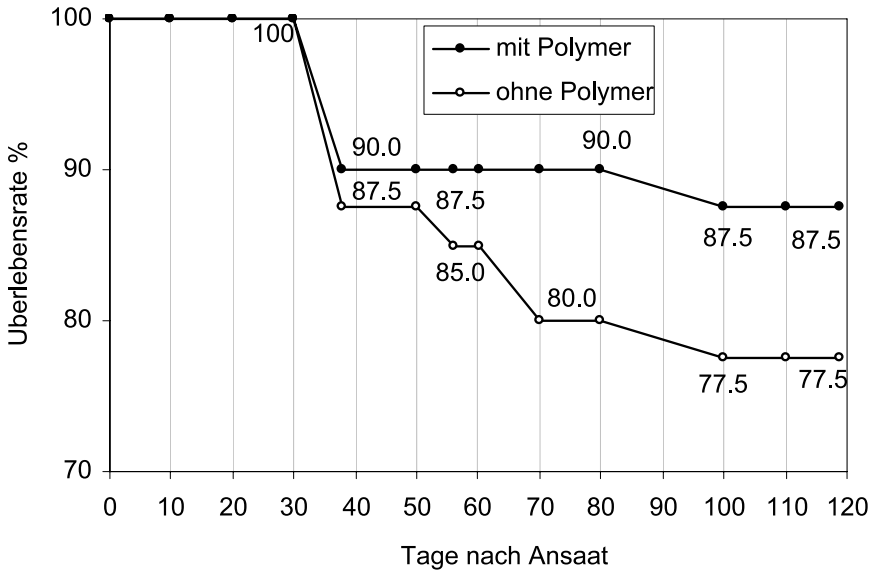
<sup>1</sup>: unterschiedliche Buchstaben zeigen signifikante Hauptwirkungen A bzw. B ( $\alpha, \beta, \gamma$ ) bzw. Wechselwirkungen A × B ( $a - e$ ) an

<sup>2</sup>: transformierte Daten

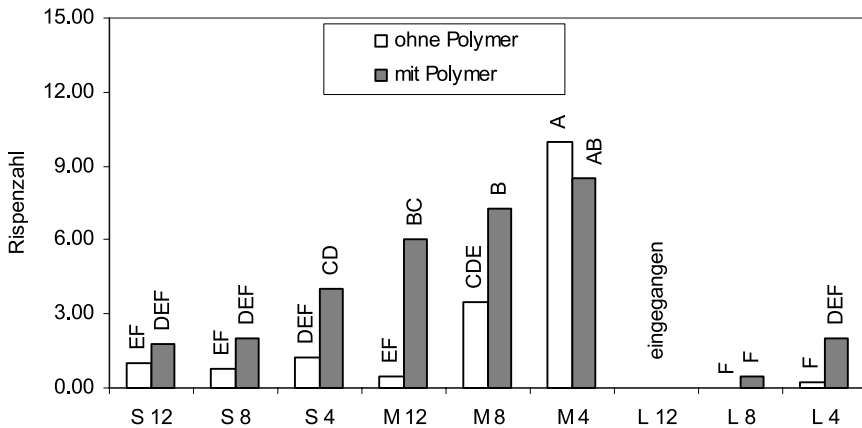
te. Ausnahme bildeten die Kombination L12, wo alle Pflanzen abgestorben waren, und M4, bei der ohne Polymergaben höchste Rispenanzahlen und Trockenmassen erreicht wurden. Signifikant war der Polymer-Effekt bei den Kombinationen (S8), S4, M12 und M8, bei welchen halbwegs passable Wachstumsbedingungen (s. u.) auch ohne Polymergaben noch eine mäßige Ausprägung zu liessen. Dies zeigt sich auch an der zunehmenden Polymer-Wirksamkeit von leichten, über den schweren, zum mittleren Boden (Tab. 4).

Effekte der polymeren Bodenverbesserer auf die Pflanzen könnten unmittelbar über die erhöhte Wasserspeicherfähigkeit der Böden, aber auch indirekt über eine verminderte Nährstoffauswaschung bei überschüssigem Regen wirksam werden. Deshalb wurden die Feldkapazität und N-Menge in Sickerwasser untersucht. Der Wassergehalt bei Feldka-

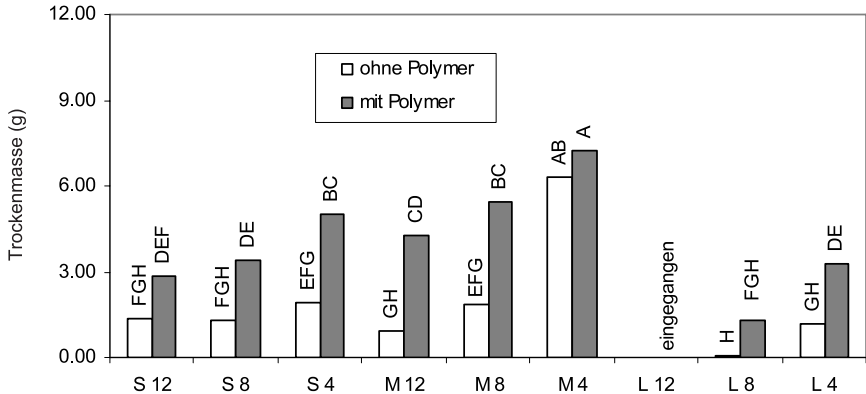
**Abbildung 1:** Wirkung des polymeren Bodenverbessers auf die Überlebensrate von Hirse.



**Abbildung 2:** Wechselwirkungen von Polymerzusatz, Bewässerung und Boden auf die Rispenanzahl von Hirsepflanzen am Versuchsende. (Bewässerung: 12/8/4 =12-, 8- und 4-tägig; Boden: L=leicht, M=mittel, S=schwer; gleiche Buchstaben bedeuten keinen signifikanten Unterschied bei  $p < 0.05$ ).



**Abbildung 3:** Wechselwirkungen von Polymerzusatz, Bewässerung und Boden auf die Trockenmassenbildung (g) von Hirsepflanzen am Versuchsende. (Bewässerung: 12/8/4 =12-, 8- und 4-tägig; Boden: L=leicht, M=mittel, S=schwer; gleiche Buchstaben bedeuten keinen signifikanten Unterschied bei  $p < 0.05$ )



**Tabelle 4:** Wechselwirkung<sup>1</sup> zwischen Boden (B) und Polymerzusatz (C) auf die Trockenmasse von Hirse (g/Pflanze) am Versuchsende.

Bodenart	Polymerzusatz	
	ohne	mit
leicht	0.42 <sup>d</sup>	1.51 <sup>c</sup>
mittel	3.03 <sup>b</sup>	5.64 <sup>a</sup>
schwer	1.51 <sup>c</sup>	3.77 <sup>b</sup>

<sup>1</sup>: unterschiedliche Buchstaben zeigen signifikante Unterschiede zwischen Mittelwerten an.

pazität erhöhte sich durch die Polymere um 15 % (Tab. 5). Hinsichtlich der N-Menge im Sickerwasser (Tab. 6) ergaben sich als Hauptwirkungen eine Zunahme von der 4- zur 8-tägigen Bewässerung (A) bzw. von leichten zum schweren Boden (B) und eine Reduktion durch den Polymerzusatz (C). Zwischen Boden (B) und Bewässerung (A) bestand eine Wechselwirkung derart, dass die 4-tägige Bewässerung zwar generell niedrige N-Werte im Dränwasser der 3 Böden als die 8-tägige Bewässerung hervorrief, dies aber bei mittlerem Boden nur tendenziell erkennbar war.

**Tabelle 5:** Hauptwirkungen<sup>1</sup> von Polymerzusatz (C) und Boden (B) auf den Bodenwasser-  
gehalt bei Sättigung<sup>2</sup> [% G/G]

C Polymerzusatz		B Boden		
ohne	mit	leicht	mittel	schwer
34.3 <sup>α</sup>	49.1 <sup>β</sup>	30.5 <sup>α</sup>	44.3 <sup>β</sup>	50.5 <sup>γ</sup>

<sup>1</sup>: B×C *n.s.*; unterschiedliche Buchstaben  $\alpha, \beta, \gamma$  indizieren signifikante Mittelwertunterschiede.

<sup>2</sup>: aus Gewichten bei Wassersättigung und stark luftgetrockneten Böden ermittelt

**Tabelle 6:** Wechselwirkung zwischen Boden (B), Bewässerung (A)<sup>1</sup> bzw. Polymerzu-  
satz (C) hinsichtlich den N-Konzentrationen im Dränwasser [mg N/l], an 2  
Terminen nach N-Gabe ohne Berücksichtigung von 12-tägiger Bewässerung  
(s.Text).

Boden B	Bewässerung A		Polymerzusatz C		Mittel B
	4-tägig	8-tägig	ohne	mit	
leicht	295 <sup>c</sup>	766 <sup>b</sup>	Keine signifikante Wirkung B×C		531 <sup>β</sup>
mittel	572 <sup>bc</sup>	664 <sup>b</sup>			618 <sup>β</sup>
schwer	631 <sup>b</sup>	1348 <sup>a</sup>			990 <sup>α</sup>
Mittel A/C	500 <sup>a</sup>	926 <sup>b</sup>	884 <sup>α</sup>	542 <sup>β</sup>	–

<sup>1</sup>: B×A signifikant; unterschiedliche Buchstaben zeigen Hauptwirkungen A,B bzw. C ( $\alpha, \beta, \gamma$ )  
bzw. Wechselwirkungen A×B (*a – e*)

#### 4 Diskussion

Die phänologischen Beobachtungen zeigten, dass die Entwicklung der Futterhirse durch eine Zunahme der Bewässerungshäufigkeit bzw. durch die Polymerzugabe begünstigt war. Dies lässt sich wahrscheinlich auf bessere Wachstumsbedingungen zurückführen und stimmt überein mit einer schnelleren phänologischen Entwicklung und einem besseren Wachstum verschiedener Gemüse- und Zierpflanzen in Folge von Polymerzugabe zum Boden in Untersuchungen von KING *et al.* (1973); FERRAZZA (1974); BEARCE und MCCOLLUM (1977) (zitiert in GEHRING und LEWIS III (1980)). Verbesserte Wachstumsbedingungen spiegeln sich auch in den Überlebensraten wieder, welches an den Sämlingen von *Pinus halepensis* (HÜTTERMANN *et al.*, 1997) durch Polymerzusatz von 0, 0,2 bzw. 0,4 % zum Boden bereits 17 TnS von 38 auf 50 bzw. 100 % festgestellt werden konnte. Auch der Anteil lebender Pflanzen von *Populus euphratica* konnte durch Zusatz von 0,6 % Polymer zu gips- und salzhaltigem Boden nach 60tägig-



gem Wachstum von 46 auf 90 % gefördert werden (HÜTTERMANN *et al.*, 1997). Diese Ergebnisse stimmen mit der zwischen dem 40. und 100. TnS zunehmenden Steigerung der Überlebensrate von Futterhirse durch Polymere überein, welche allgemein von einer Zunahme der Rispenanzahl, Höhe und TM je Pflanze begleitet war. Grundsätzlich können diese Wirkungen an Futterhirse auf eine verbesserte Wasserspeicherung zurückgeführt werden, wie dies analog von GEHRING und LEWIS III (1980) und WEAVER *et al.* (1977) beschrieben wurde. Auch in anderen Arbeiten wird eine verbesserte Wasserspeicherung aufgrund von Polymeren als Ursache für ein verlängertes Überleben von Mais und Bohnen (BAKASS *et al.*, 2002) und für eine bessere Turgeszenz von Erdnuss (MOHANA RAJU *et al.*, 2002) bei knappen Wasserangebot angesehen.

Um die Wechselwirkungen zwischen Polymergabe und den Faktoren Boden bzw. Bewässerung zu bewerten, ist es notwendig zunächst die Wechselwirkung Boden-Bewässerung zu betrachten. Auf mittlerem Boden (und eingeschränkt auch bei leichtem) erhöhte eine zunehmende Bewässerungsfrequenz die Rispenanzahl und Trockenmasse von Futterhirse stufenweise, was auf Wassermangel als begrenzender Faktor für das Wachstum hinweist. Bei dem schweren Boden hatte die Bewässerung keinen bzw. nur einen schwachen Effekt. Hieraus ist zu schlussfolgern, dass Wassermangel zumindest nicht der einzige begrenzende Faktor war. Da der schwere Boden sich von mittleren nur durch einen höheren Ton- zulasten des Schluffgehaltes unterschied, dürfte dessen nutzbare Feldkapazität - trotz des höheren Wassergehalts bei Sättigung - aufgrund eines erheblich höheren Totwassergehaltes etwas geringer, aber besonders der Grobporenanteil deutlich geringer sein (SCHACHTSCHABEL *et al.*, 1989). Letzteres dürfte eine schlechte Belüftung bedingen und neben geringerer P- und K-Verfügbarkeit Ursache für eine verminderte Rispen- und TM-Bildung bei Futterhirse auf dem schweren im Vergleich zum mittleren Boden sein. Insofern ist davon auszugehen, dass bei höherer Bewässerungsfrequenz die schlechte Belüftung des schweren Bodens durch Verschlammung der Bodenoberfläche und Stauwasser noch verstärkt wurde und somit die positive Wirkung einer besseren Wasserversorgung abmilderte bzw. überdeckte.

Allgemein war die günstige Wirkung der **Polymergabe** in Verbindung mit den verschiedenen **Boden-Bewässerungskombinationen** bezüglich der Rispen- und TM-Bildung sehr ähnlich. Auf **mittlerem Boden** war eine fördernde Wirkung der Polymergabe bei geringer und mittlerer Bewässerungsfrequenz (M 12 und M 8) deutlich erkennbar, was einer Minderung des Wassermangels zugeschrieben werden kann. Die Wirkungslosigkeit der Polymergabe bei hoher Bewässerungshäufigkeit ist mit einer an sich günstigen Wasserversorgung dieser Boden-Bewässerungskombination zu erklären. Diese Ergebnisse belegen, dass es möglich ist, die Bewässerungsfrequenz durch Polymergabe von 4- auf 8-tägig ohne Nachteil zu reduzieren. Zu ähnlicher Schlussfolgerung gelangten HÜTTERMANN *et al.* (1997) in Versuchen an *Populus*, in denen die Bewässerung in einem längeren Intervall reduziert wurde und ein vermindertes Wachstum je nach Höhe der Polymerzugabe erst deutlich verzögert eintrat. Auch Experimente von DEHGAN *et al.* (1994); DEHGAN (1995) sowie STILL (1976) weisen in die gleiche Richtung. Auf **schwerem Boden** hatte die Bewässerungsfrequenz kaum einen Effekt auf die Rispenanzahl und TM, dennoch wirkten Polymergaben bei S 12, S 8 und S 4 in ähnlichem Umfang (tendenziell

bzw. signifikant, Abb. 2 und 3). Dies könnte auf einer Minderung von Verschlammung und Stauwasser infolge eines durch Polymere verbesserten, stabileren Bodengefüges beruhen.

Auf dem **leichten Boden**, einem humusarmen Sand, war die Wasserspeicherung allgemein so gering, so dass ohne polymere Bodenverbesserer nur bei hoher Bewässerungsfrequenz eine sehr geringe Rispen- und TM-Bildung möglich war, welche mit Polymergabe schon bei mittlerer Frequenz erreicht wurde und bei hoher Frequenz noch deutlich überoffen wurde. Auf sehr leichtem Boden ist allerdings eine angemessene Hirseproduktivität nur bei hoher Bewässerungsfrequenz und Polymereinsatz zu erzielen. In die gleiche Richtung weisen Untersuchungen von GEESING und SCHMIDHALTER (2004), in denen eine signifikante Erhöhung der Trockenmasse bei Weizen nur erzielt wurde, wenn durch die Polymere ein Wassermangel vermieden wurde.

Insgesamt zeigen die Untersuchungen, dass Polymereinsatz auf mittleren und leichten Böden die Wasserversorgung und die Produktivität von annuellen Pflanzen wie Futterhirse verbessern kann, und bei mittlerem Boden die notwendige Bewässerungsfrequenz und damit auch Arbeit sowie Kosten gesenkt werden können. Dies bestätigen Untersuchungen von SIVAPALAN (2001a), anhand steigender Erträge von Sojabohnen aufgrund zunehmender Polymergaben bzw. gleicher Erträge, wenn bei höherer Polymerzugabe die Bewässerungsfrequenz erniedrigt wurde.

In einer weiteren Arbeit belegte SIVAPALAN (2001b) auf leichtem Boden eine verbesserte Wasserspeicherung durch Polymerzusatz, welche in unserem Versuch auf allen drei Böden auch die N-Auswaschung verringerte. Dabei ist die unerwartete höhere N-Auswaschung bei 8-tägiger im Vergleich zur 4-tägigen Bewässerung vermutlich auf die geringere Biomassebildung (Tab. 4) bzw. damit auch verringerter N-Aufnahme durch die Pflanzen nach der zweiten N-Gabe zur Blüte zurückzuführen. Die Versuche von SYVERTSEN und DUNLOP (2004) weisen auch darauf hin, dass durch Polymerzusatz zu einem Sandboden die N-Aufnahme von Citrussämlingen zunahm und darüber hinaus auch eine N-Auswaschung dort verhindert wurde.

Es bleibt zu prüfen, ob die allgemeine Förderung der Pflanzen durch Polymerzugabe auf schweren Böden (s u L) eventuell auf einer Strukturverbesserung des Bodens im Sinne einer besseren Belüftung beruhte.

## **Effects of a Polymer for Soil Amendation on Yield Formation of Millet under Arid Conditions**

### **Summary**

In arid and semiarid regions water is one of the main limiting factor for plant production. With regard to advantages of an improved water-holding capacity in such regions, we investigated the effects of polymer addition (0,3 % w/w) to three soils (light, medium and heavy) and of three irrigation frequencies (every 4, 8 or 12 days) on the survival and growth of *Panicum antidotale* Retz and on nitrogen leaching under the climatic conditions of north-west Iran.

40 d after sowing survival rate of millet decreased progressively, particularly on the light soil and at a low irrigation frequency. Polymer admixtures and high irrigation frequencies provoked marked positive effects on all plant traits with significant interactions with soils. On all soils, but particularly on the medium soil which favored panicle and biomass production, the effects of polymers were most pronounced at low and medium irrigation frequencies. The interactions are discussed on the background of an improved water-holding capacity, a better soil aeration, and a reduced leaching of nitrogen due to the polymer admixture.

Keywords: polymer admixture, water-holding capacity, irrigation frequency, millet, *Panicum antidotale*, nitrogen leaching, survival rate

## Literatur

- ANONYMOUS; Polymer gel holds water for tree seedlings; *S A Forestry*, July/August; 1998.
- BAKASS, M., A. MOKHLISSE und M. LALLEMANT; Absorption and Desorption of Liquid Water by a Superabsorbent Polymer: Effect of Polymer in the Drying of the Soil and the Quality of Certain Plants; *Journal of Applied Polymer Science*; 83:234–243; 2002.
- BARUAH, T. C. und H. P. BARTHAKUR; *A Textbook of Soil Analysis*; Vikas Publishing House PVT LTD; 1997.
- BEARCE, B. C. und R. W. MCCOLLUM; A comparison of peat-like and noncomposted hardwood-bark mixes for use in pot and bedding-plant production and the effects of a new hydrogel soil amendment on their performance; *Flor. Rev.*; 161(4169):21–23,66–67; 1977.
- BOWMAN, D. C., R. Y. EVANS und J. L. PAUL; Fertilizer salts reduce hydration of polyacrylamide gels and affect physical properties of gel-amanded container media; *Journal American Soc. Hort. Sci.*; 115(3):382–386; 1990.
- COTTENIE, A.; Soil and Plant testing as a basic of fertilizer recommendation; *FAO Soil Bulletin*, 38/2, Rome; 1980.
- DEHGAN, B.; Using polymers in landscape trees- preliminary research shows that polymers result in less irrigation; *Ornamental Outlook*; 4:17–18; 1995.
- DEHGAN, B., T. H. YEAGER und F. C. ALMIRA; Photinia and podocarpus growth response to a hydrophilic polymer amendend medium; *Hort. Sci.*; 29(6):641–644; 1994.
- FERRAZZA, J.; Grower evaluates soil amendment; *Flor. Rev.*; 155(4019):27, 69–70; 1974.
- FINCK, A.; *Dünger und Düngung*; Verlag Chemie, Weinheim, New York; 1992.
- GEESING, D. und U. SCHMIDHALTER; Influence of sodium polyacrylate on the water-holding capacity of three different soils and effects on growth of wheat; *Soil Use and Management*; 20:207–209; 2004.
- GEHRING, J. M. und A. J. LEWIS III; Effekt of Hydrogel on Wilting and Moistre Stress of Bedding Plants; *Journal American Soc. Hort. Sci.*; 105(4):511–513; 1980.
- HÜTTERMANN, A., K. REISE, M. ZOMORRODI und S. WANG; The use of hydrogels for afforestation of difficult stands: water and salt stress; in: ZHOU, H. und

- H. WEISGERBER (Herausgeber), *Afforestation in semi-arid regions*; S. 167 – 177; Datong/Jinshatan, China; 1997.
- HÜTTERMANN, A., M. ZOMMORODI und K. REISE; Addition of hydrogels to soil for prolonging the survival of *Pinus halepensis* seedlings subjected to drought; *Soil and Tillage Research*; 50:295–304; 1999.
- KING, P. A., R. H. EIKHOF und M. H. JENSEN; The influence of insolubilized poly(ethylene oxide) in the soil-plant-water matrix: its effect on vegetable crops; Proc. 11th Nat. Agric. Plastics Conf.; 1973.
- MOHANA RAJU, K., M. PADMANABHA RAJU und Y. MURALI MOHAN; Synthesis and Water Absorbency of Crosslinked Superabsorbent Polymers; *Journal of Applied Polymer Science*; 85:1795–1801; 2002.
- ROWELL, D. L.; *Bodenkunde. Untersuchungsmethoden und ihre Anwendungen*; Springer-Verlag Berlin; 1994.
- SCHACHTSCHABEL, P., H.-P. BLUME, G. BRÜMMER, K.-H. HARTGE und U. SCHWERTMANN; *Lehrbuch der Bodenkunde*; F. Enke Verlag Stuttgart; 1989.
- SCHINNER, F., R. ÖHLINGER und E. KANDELER; *Bodenbiologische Arbeitsmethoden*; Springer-Verlag Berlin, Heidelberg; 1991.
- SCHLICHTING, E., H. P. BLUME und K. STAHR; *Bodenkundliches Praktikum*; Pareys Studentexte 81; Blackwell Wissenschafts-Verlag Berlin, Wien; 1995.
- SIVAPALAN, S.; Effect of a Polymer on growth and yield of Soyabeans (*Glycine max*) grown in a coarse textured soil; Proceedings of the Irrigation Association of Australia Conference, Toowoomba, 11-12 July, pp. 28-32; 2001a.
- SIVAPALAN, S.; Effect of a Polymer on soil water holding capacity and plant water use efficiency; Pro. 10th Aust. Agron. Conf. Hobart. [www.regional.org.au/asa](http://www.regional.org.au/asa); 2001b.
- STILL, S. M.; Growth of Sunny Mandalay chrysanthemums in hardwood-bark-amended media as affected by insolubilized poly(ethylene oxide); *Hort. Sci.*; 11:483–484; 1976.
- SYVERTSEN, J. P. und J. M. DUNLOP; Hydrophilic gel amendments to sand soil can increase growth and nitrogen uptake efficiency of citrus seedlings; *HortScience*; 39:267–271; 2004.
- WANG, Y. T. und L. L. GREGG; Hydrophilic polymers: Their response to soil amendments and effect on properties of a soilless potting mix; *Journal American Soc. Hort. Sci.*; 115(6):943–948; 1990.
- WEAVER, M. O., R. R. MONTGOMERY, L. D. MILLER, V. E. SOHNS, G. F. FANTA und W. M. DOANE; A practical process for the preparation of super slurper, a starch-based polymer with a large capacity to absorb water; *Die Stärke*; 29(12):410–413; 1977.

## Variation in the Response of Seed and Embryonic Axes to Incubation Temperature Gradients during Seed Treatments in Pearl Millet and Sorghum

M. A. Kader<sup>1</sup>

### Abstract

Incubation temperature during the presowing soaking of seeds plays a significant role in determining the rate and characteristics of post-treatment germination. Three experiments were conducted on sorghum (*Sorghum bicolor* L Moench) and pearl millet (*Pennisetum glaucum* L. R. Br.) genotypes to determine the influence of constant, alternating, ascending and descending temperature regimes on germination characteristics of seeds after treatment. Incubation temperatures ranging from 10 to 35°C were applied as well as alternating the magnitude and range of day/night temperatures. A third experiment tested a 3-day temperature gradient and its impact on germination and seedling characteristics. All three incubation temperature regimes were combined with various hormonal and mineral seed soaking treatments to test for possible interactive effects. Temperature did not affect the final germination percentage of seeds but influenced the germination rate. Constant temperatures of 20 or 25°C induced higher germinative capacity than alternating or constant temperatures of higher or lower magnitude. Increasing the variance in day/night temperature reduced the rate of germination. Incubating seeds during soaking treatments at a constant 20°C for 3 days yielded better germination characteristics than a thermal gradient of 25/20/15°C. An 8g l<sup>-1</sup>NaCl treatment induced greater plumule (shoot) growth than non-treated counterparts and treating seeds with GA<sub>3</sub> or salts improved germination characteristics and synchrony of treated seed lots.

**Keywords:** seed treatments, treatment temperature, germination, plumule, radicle

### 1 Introduction

Emergence and establishment of rainfed sorghum and pearl millet may not always be completely successful since, after imbibition, any water shortage delays emergence, exposing the seeds to stress (AL-MUDARIS, 1998b; KADER, 2001; KADER and JUTZI, 2001). Therefore, there has recently been an upsurge of interest in the use of presowing seed treatments involving full or partial hydration of seeds, which may improve emergence and subsequent establishment (GURUSHINGHE *et al.*, 1999; POWELL *et al.*, 2000; GALLARDO *et al.*, 2001; HARRIS, 2001; ARAUS *et al.*, 2002; KADER and JUTZI, 2002).

---

<sup>1</sup> Mohamad A. Kader, Director, Consultica Worldwide, PO Box 3089 Tamarama NSW 2026 Australia, m.kader@mbox.com.au

Such treatments include the soaking of seeds in high osmotic potential solutions for various periods of time (HEYDECKER, 1978; HEYDECKER and GIBBINS, 1978; BROCKLEHURST and DEARMAN, 1984; DEMIR and VAN DE VENTER, 1999; GOSLING *et al.*, 1999; LIN and SUNG, 2001). Temperature, which is an important variable in such treatments, has both qualitative and quantitative effects on subsequent germination rates of treated seeds (HEYDECKER *et al.*, 1973; ARGERICH and BRADFORD, 1989; HARDEGREE, 1994; HAMPTON *et al.*, 2000). Reports on the optimum incubation temperature have been inconsistent and do not lend themselves to easy interpretation. BOOTH (1992) imbibed seeds of *Eurotica lanata* at temperatures from 0 to 20°C in 5°C increments and found that as imbibition temperature increased from 5 to 15°C the probability of successful germination after soaking decreased. BROCKLEHURST and DEARMAN (1984) primed carrot, celery, leek and onion seeds at 15°C, whereas RENNICK and TIERNAN (1978) used 18°C. Other treatment temperatures have been reported ranging from 20°C for carrot (AUSTIN *et al.*, 1969) to 25°C for pepper seed (GEORGHIU *et al.*, 1987) spanning a wide array of temperature gradients (WELBAUM *et al.*, 1998; PRITCHARD *et al.*, 1999; KOLASINSKA *et al.*, 2000; STEINMAUS *et al.*, 2000; IANNUCCI *et al.*, 00; WUEBKER *et al.*, 2001). The priming of sorghum and pearl millet has not been well documented in the literature, and investigation of the effects of both constant and alternate priming temperature gradients is important in stress acclimation treatments (AL-MUDARIS, 1998b; GLENN and BROWN, 1998). The objective of the experiments reported here was to study the influence of incubation temperature during priming with various agents on subsequent germination rate of sorghum (*Sorghum bicolor* L. Moench) and pearl millet (*Pennisetum glaucum* L. R. Br.) seeds. Both constant and alternate temperature regimes were tested in addition to a sequential regime involving gradual temperature increases or decreases throughout the treatment period, thus creating a temperature gradient.

## 2 Materials and Methods

### 2.1 Constant incubation temperatures

Four seed treatments including a dry control were applied to four sorghum and pearl millet genotypes. All four accessions were obtained from the Asia Centre of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru, India. These included sorghum varieties ICSV 745 and M35-1, the pearl millet variety CZ-IC 923 and the pearl millet hybrid HHB 67. All seeds were tested following International Seed Testing Association regulations (ISTA, 1993) and revealed germination percentages of 95.7 to 99.3%, moisture content of 13.3 to 14.9% and viability (tetrazolium) of 99.7 to 100%. One thousand (1000) seed weights were 30.3, 38.9, 13.3 and 13.5g for ICSV 745, M35-1, CZ-IC 923 and HHB 67, respectively.

Seed treatments included soaking seed in 150 mg l<sup>-1</sup> gibberellic acid (GA<sub>3</sub>) (150 ppm), 150 mg l<sup>-1</sup> kinetin (150 ppm), 5g KNO<sub>3</sub> l<sup>-1</sup> (5%) or 5g l<sup>-1</sup> NaCl (5%) for 3 days (d). The control included dry, untreated seeds. All 4 seed treatments and the dry control were incubated during the 3-day (d) period at one of six temperatures. These were 10, 15, 20, 25, 30 or 35°C in incubation chambers in the dark (Convicon Industries,

Canada). After treatment, seeds were retrieved from solutions, washed in distilled water and sown in 1-litre polystyrene trays. Two hundred (200) seeds were sown per tray between creased filter paper and each treatment combination replicated 6 times. Trays were placed in a germination cabinet set at a constant 35°C temperature in the dark to allow germination. Germination counts were taken at 24 hour (h) intervals for 10 d and from them the final germination percentage (FGP), first day of germination (FDG), mean germination time (MGT) and germination rate index (GRI) calculated. MGT and GRI were calculated following ORCHARD (1977) and BENECH ARNOLD *et al.* (1991), respectively. Data were arcsine transformed (YANG *et al.*, 1999; HOULE *et al.*, 2001) and subjected to an analysis of variance with mean separation at the 5 % level of probability using the General Linear Model of the SAS® statistical package (SAS Institute, USA) (SAS, 1989; BARRILLEAUX and GRACE, 2000). Trays were arranged in a Randomised Complete Block Design (RCBD) inside incubators and data exposed to one-way and two-way ANOVA (WEBER and ANTONIO, 1999).

## 2.2 Alternating incubation temperatures

A dry, untreated and a wet, water-soaked (distilled water) control were included in this experiment in addition to two sodium chloride-based (NaCl) treatments. These were 4 and 8g l<sup>-1</sup>NaCl solutions having an osmometer-measured (Wescor, Utah, USA) osmotic potential ( $\Psi_s$ ) of -3.2 and -5.7 bar, respectively (circa -0.3 and -0.5 MPa, respectively).

Seeds of sorghum SPV 462, an ICRISAT variety, were either untreated (dry control), soaked in distilled water (wet control) or soaked in the NaCl solutions for 3 d. Incubation temperatures during treatment included a constant 25°C regime and 3 alternate regimes. These were 25/20°C (12 h/12 h day/night), 25/15°C and 25/10°C. Treatments were conducted in the dark. After treatment, seeds were washed in distilled water and dried back at 25°C for 48 h to their original weight in a constant air flow cabinet (Heraeus Voetsch, Germany). Batches of 200 seeds were then sown in 1-liter polystyrene trays between creased filter paper. The paper was moistened with 50 ml of a polyethylene glycol solution (PEG molecular weight 10,000 Sigma Chemical, St Louis, USA) producing a drought level of -10 bar (-1 MPa). As an osmotic agent, PEG is metabolically inert and is ideal for simulating drought (SALISBURY and ROSS, 1992; SWAGEL *et al.*, 1997).

Trays were covered with transparent lids, replicated 6 times and placed in an incubator at 42/18°C (12 h/12 h day/night). Germination was scored daily for a period of 10 d and from the data the FGP, MGT and germination index (GI) were calculated (AL-MUDARIS, 1998a). GI assigns maximum weight to seeds germinating on the first day and less weight to seeds germinating thereafter (BENECH ARNOLD *et al.*, 1991). At the end of the test, 20 seedlings were randomly taken from the 20 middle creases in the filter paper and their plumules and radicles excised and weighed after drying at 80°C for 4 d in a reverse cycle oven (Convion Industries, Canada). These produced the dry weight of plumule (DWP), dry weight of radicle (DWR) and the plumule to radicle ratio (PRR), which is the product of DWP divided by DWR. Statistical procedures were similar to the constant incubation temperature experiment.

### 2.3 Ascending and descending temperatures

The same batch of SPV 462 seeds was used in this test. Seeds were either untreated (dry control), soaked in 4g NaCl l<sup>-1</sup> (4%) or soaked in 4g l<sup>-1</sup> KCl (4%) for 3 d. Three temperature regimes were applied during soaking treatments as follows:

Regime 1 (R1): Seeds in soaking solutions exposed to 25°C on the first day of treatment, 20°C on the second day and 15°C on the third day.

Regime 2 (R2): Seeds in soaking solutions exposed to 15°C on the first day of treatment, 20°C on the second day and 25°C on the third day.

Regime 3 (R3): Seeds exposed to a continuous 20°C during the whole 3 d treatment period.

Seeds were retrieved from the solutions, dried as in the previous experiment and sown in batches of 200 in polystyrene trays in 6 replicates. Fifty (50) ml of the -10 bar PEG solution was applied to each tray and, thereafter, trays incubated at 39/15°C (12 h/12 h day/night) in the dark. Germination scores were taken daily for the first 10 d and the FGP, MGT and GI calculated. On the 11<sup>th</sup> day, 20 seedlings were randomly taken as in the previous experiment and their DWP, DWR and PRR recorded.

## 3 Results and Discussion

### 3.1 Constant incubation temperatures

Single factor analysis showed that soaking treatments did not have a significant effect on the FGP or GRI of sorghum or pearl millet seed (Table 1). Germination speed as reflected by the FDG and MGT was, however, significantly increased by seed treatments in comparison to controls. GA<sub>3</sub> generally gave the fastest germination (Table 1).

Genotypes differed significantly in their germination characteristics (Table 1). The sorghum variety ICSV 745 gave the highest overall FGP and GRI pooled over treatments and incubation temperatures followed by the pearl millet variety CZ-IC 923, the hybrid HHB 67 and the sorghum variety M35-1. The slowest initiation and rate of germination were observed in HHB 67 as illustrated in Table 1. Incubation temperature also had a significant effect on the FGP, FDG, MGT and GRI. The 35°C incubation temperature resulted in the lowest FGP followed by 30°C, whereas the 10°C regime caused germination to initiate later and take longer time to complete. The 25°C regime was optimal in terms of this initiation and ending of germination as seen from FDG and MGT values (Table 1).

Interactive analysis of genotype×temperature effects (Table 2) revealed the same trend. Thirty and 35°C reduced the FGP and germination speed was generally increased by an increase in incubation temperature. Seed treatment × genotype analysis showed no general preference of a genotype to one specific treatment (data not shown). The same applied to seed treatment×incubation temperature effects, where no single treatment generally preferred a particular temperature but rather an overall effect of temperature in reducing the FGP as it rose to 35°C was detected (data not shown).



**Table 1:** Effect of seed treatments, genotype and incubation temperature on germination characteristics of sorghum and pearl millet.

	<i>FGP (%)</i>	<i>FDG (day)</i>	<i>MGT (day)</i>	<i>GRI (%/day)</i>
<i>Seed Treatment</i>				
Dry Control	65.8 <sup>a</sup>	3.6 <sup>a</sup>	3.8 <sup>a</sup>	15.4 <sup>a</sup>
GA <sub>3</sub>	67.6 <sup>a</sup>	3.3 <sup>b</sup>	3.4 <sup>b</sup>	16.3 <sup>a</sup>
<i>Kinetin</i>				
64.2 <sup>a</sup>	3.5 <sup>ab</sup>	3.6 <sup>b</sup>	15.1 <sup>a</sup>	
KNO <sub>3</sub>	64.1 <sup>a</sup>	3.5 <sup>a</sup>	3.6 <sup>ab</sup>	15.4 <sup>a</sup>
NaCl	63.6 <sup>a</sup>	3.5 <sup>a</sup>	3.6 <sup>ab</sup>	14.4 <sup>a</sup>
<i>Genotype</i>				
ICSV 745	87.0 <sup>a</sup>	3.3 <sup>b</sup>	3.4 <sup>b</sup>	22.1 <sup>a</sup>
M35-1	45.2 <sup>d</sup>	3.4 <sup>b</sup>	3.5 <sup>b</sup>	10.3 <sup>d</sup>
CZ-IC 923	66.1 <sup>b</sup>	3.5 <sup>b</sup>	3.6 <sup>b</sup>	15.6 <sup>b</sup>
HHB 67	62.0 <sup>c</sup>	3.7 <sup>a</sup>	3.8 <sup>a</sup>	13.3 <sup>c</sup>
<i>Incubation Temp. (°C)</i>				
10	71.3 <sup>a</sup>	3.9 <sup>a</sup>	4.0 <sup>a</sup>	14.8 <sup>ab</sup>
15	71.8 <sup>a</sup>	3.6 <sup>b</sup>	3.7 <sup>b</sup>	15.5 <sup>ab</sup>
20	70.3 <sup>a</sup>	3.4 <sup>b</sup>	3.5 <sup>b</sup>	16.0 <sup>a</sup>
25	68.2 <sup>a</sup>	3.1 <sup>c</sup>	3.2 <sup>c</sup>	17.2 <sup>a</sup>
30	58.5 <sup>b</sup>	3.4 <sup>b</sup>	3.5 <sup>c</sup>	15.2 <sup>ab</sup>
35	50.3 <sup>c</sup>	3.5 <sup>b</sup>	3.6 <sup>b</sup>	13.2 <sup>b</sup>

Means of treatment effects within columns followed by a similar letter are not significantly different at 5%. The same applies to means of genotype and incubation temperature effects. FGP: Final Germination Percentage, FDG: First Day of Germination, MGT: Mean Germination Time and GRI: Germination Rate Index.

### 3.2 Alternating incubation temperatures

The FGP of dry controls was significantly higher than that of either the wet control or the two NaCl treatments. However, the MGT of the dry control was also higher meaning that it germinated slower than those seeds that were soaked (Table 3). Due to the higher FGP of the dry control it attained a higher GI value at the end of the test. The dry weight of plumules of seeds treated with the 8g l<sup>-1</sup> NaCl solution was significantly greater than those of all other treatments (Table 3), which did not differ from each other in this respect. The DWR and PRR did not differ amongst treatments.

**Table 2:** Interactive effects of genotype and incubation temperature on germination characteristics of sorghum and pearl millet.

<i>Genotype</i>	<i>Incubation Temp. (°C)</i>	<i>FGP (%)</i>	<i>FDG (day)</i>	<i>MGT (day)</i>	<i>GRI (%/day)</i>
ICSV 745	10	87.5 <sup>ab</sup>	4.1 <sup>ab</sup>	4.1 <sup>ab</sup>	18.7 <sup>b-d</sup>
	15	92.5 <sup>a</sup>	3.8 <sup>b-d</sup>	3.8 <sup>b-d</sup>	20.9 <sup>a-c</sup>
	20	86.0 <sup>b</sup>	3.4 <sup>d-f</sup>	3.6 <sup>d-f</sup>	20.9 <sup>a-c</sup>
	25	88.0 <sup>ab</sup>	3.2 <sup>e-g</sup>	3.3 <sup>e-g</sup>	23.3 <sup>ab</sup>
	30	85.0 <sup>b</sup>	2.9 <sup>gh</sup>	2.9 <sup>g</sup>	24.0 <sup>a</sup>
	35	83.0 <sup>bc</sup>	2.7 <sup>h</sup>	2.8 <sup>g</sup>	24.9 <sup>a</sup>
M35-1	10	42.0 <sup>gh</sup>	4.0 <sup>a-c</sup>	4.1 <sup>a-c</sup>	8.1 <sup>i</sup>
	15	47.5 <sup>gh</sup>	3.6 <sup>de</sup>	3.6 <sup>de</sup>	9.2 <sup>hi</sup>
	20	51.5 <sup>g</sup>	3.5 <sup>d-f</sup>	3.6 <sup>d-f</sup>	11.8 <sup>e-i</sup>
	25	48.5 <sup>f-h</sup>	3.2 <sup>e-g</sup>	3.2 <sup>e-g</sup>	10.4 <sup>g-i</sup>
	30	45.0 <sup>gh</sup>	3.5 <sup>d-f</sup>	3.6 <sup>d-f</sup>	11.7 <sup>e-i</sup>
	35	37.0 <sup>h</sup>	2.9 <sup>gh</sup>	2.9 <sup>g</sup>	10.6 <sup>g-i</sup>
CZ-IC 923	10	81.5 <sup>bc</sup>	3.8 <sup>b-d</sup>	3.8 <sup>b-d</sup>	17.1 <sup>cd</sup>
	15	81.5 <sup>bc</sup>	3.5 <sup>d-f</sup>	3.5 <sup>d-f</sup>	18.4 <sup>b-d</sup>
	20	68.5 <sup>de</sup>	3.4 <sup>e-f</sup>	3.5 <sup>d-f</sup>	15.7 <sup>d-f</sup>
	25	67.0 <sup>de</sup>	3.1 <sup>e-g</sup>	3.2 <sup>fg</sup>	17.0 <sup>cd</sup>
	30	60.5 <sup>ef</sup>	3.2 <sup>e-g</sup>	3.2 <sup>e-g</sup>	16.0 <sup>c-e</sup>
	35	38.0 <sup>h</sup>	4.1 <sup>ab</sup>	4.2 <sup>ab</sup>	9.4 <sup>hi</sup>
HHB 67	10	74.3 <sup>cd</sup>	3.8 <sup>a-d</sup>	3.9 <sup>b-d</sup>	15.1 <sup>e-g</sup>
	15	66.0 <sup>de</sup>	3.7 <sup>cd</sup>	3.7 <sup>c-e</sup>	13.7 <sup>e-h</sup>
	20	75.5 <sup>cd</sup>	3.4 <sup>d-f</sup>	3.5 <sup>e-f</sup>	15.5 <sup>d-f</sup>
	25	69.5 <sup>de</sup>	3.1 <sup>e-h</sup>	3.1 <sup>fg</sup>	18.1 <sup>cd</sup>
	30	43.5 <sup>gh</sup>	4.3 <sup>a</sup>	4.4 <sup>a</sup>	9.1 <sup>hi</sup>
	35	43.5 <sup>gh</sup>	4.2 <sup>a</sup>	4.4 <sup>a</sup>	8.0 <sup>i</sup>

Means in columns followed by similar letters are not significantly different at 5%.

FGP: Final Germination Percentage, FDG: First Day of Germination, MGT: Mean Germination Time and GRI: Germination Rate Index.

**Table 3:** Effect of seed treatments and incubation temperatures on germination and seedling characteristics of sorghum SPV 462 seeds.

	<i>FGP (%)</i>	<i>MGT (day)</i>	<i>GI</i>	<i>DWP (mg)</i>	<i>DWR (mg)</i>	<i>PRR</i>
<i>Seed Treatment</i>						
Dry Ctrl.	82.8 <sup>a</sup>	4.0 <sup>a</sup>	535.4 <sup>a</sup>	1.0 <sup>b</sup>	1.5 <sup>a</sup>	0.83 <sup>a</sup>
Wet Ctrl.	61.2 <sup>b</sup>	3.5 <sup>b</sup>	432.2 <sup>bc</sup>	1.3 <sup>b</sup>	1.7 <sup>a</sup>	0.88 <sup>a</sup>
4g/l NaCl	58.0 <sup>b</sup>	3.3 <sup>bc</sup>	401.7 <sup>c</sup>	1.1 <sup>b</sup>	1.6 <sup>a</sup>	0.75 <sup>a</sup>
8g/l NaCl	53.0 <sup>b</sup>	2.9 <sup>c</sup>	486.6 <sup>ab</sup>	2.0 <sup>a</sup>	2.1 <sup>a</sup>	0.97 <sup>a</sup>
<i>Incubation Temp. (°C)</i>						
25	68.5 <sup>a</sup>	3.1 <sup>b</sup>	521.4 <sup>a</sup>	1.4 <sup>a</sup>	2.3 <sup>a</sup>	0.64 <sup>a</sup>
25/20	64.9 <sup>a</sup>	3.3 <sup>b</sup>	476.1 <sup>ab</sup>	1.2 <sup>a</sup>	1.5 <sup>b</sup>	0.89 <sup>a</sup>
25/15	63.0 <sup>a</sup>	3.9 <sup>a</sup>	426.0 <sup>b</sup>	1.3 <sup>a</sup>	1.5 <sup>b</sup>	0.93 <sup>a</sup>
25/10	58.5 <sup>a</sup>	3.5 <sup>ab</sup>	432.5 <sup>b</sup>	1.5 <sup>a</sup>	1.6 <sup>ab</sup>	0.97 <sup>a</sup>

Means of treatment effects within columns followed by a similar letter are not significantly different at 5%. The same applies to means of incubation temperature effects.

FGP: Final Germination Percentage , MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle, PRR: Plumule/Radicle Ratio, Dry Control: untreated seeds, and Wet Control: Water-soaked seeds.

Incubation temperature also did not seem to have an effect on the FGP of sorghum seeds (Table 3), but affected germination speed as seen from the MGT values. The 25°C constant temperature regime gave faster germination than the 25/15°C regime. The GI was also higher for the 25°C regime than the 25/15 or 25/10°C regimes (Table 3). Neither DWP nor PRR were affected by incubation temperature even though the DWR was higher at 25°C than at 25/20 or 25/15°C.

Interactive analysis between seed treatments and temperature regimes revealed no preference of treatments for a certain temperature but a tendency of water-soaked seeds to perform better under the 25°C regime than under others (data not shown). Otherwise, the same results as those of single factor effects were observed.

### 3.3 Ascending and descending temperatures

As seen from Table 4, the 4g l<sup>-1</sup> KCl treatment, pooled over all three temperature regimes, yielded a significantly lower FGP than the dry control and the 4g l<sup>-1</sup> NaCl treatment. Again, the effect of soaking treatments was that of increasing germination speed as seen by lower MGT values in the salt soaks.

The 4g l<sup>-1</sup> NaCl treatment gave the best FGP×MGT relationship as it yielded the highest GI value. Seedling characteristics, represented by DWP, DWR and PRR were

**Table 4:** Effect of seed treatments and incubation temperature sequences on germination and seedling characteristics of sorghum SPV 462.

	<i>FGP (%)</i>	<i>MGT (day)</i>	<i>GI</i>	<i>DWP (mg)</i>	<i>DWR (mg)</i>	<i>PRR</i>
<i>Seed Treatment</i> <sup>1</sup>						
Dry Ctrl.	84.0 <sup>a</sup>	3.9 <sup>a</sup>	593.3 <sup>b</sup>	2.4 <sup>a</sup>	2.1 <sup>a</sup>	1.1 <sup>a</sup>
4g/l NaCl	84.7 <sup>a</sup>	2.9 <sup>b</sup>	678.8 <sup>a</sup>	2.6 <sup>a</sup>	2.6 <sup>a</sup>	1.0 <sup>a</sup>
4g/l KCl	78.2 <sup>b</sup>	3.3 <sup>b</sup>	593.7 <sup>b</sup>	2.8 <sup>a</sup>	2.6 <sup>a</sup>	1.0 <sup>a</sup>
<i>Incubation Temp. (°C)</i> <sup>2</sup>						
25/20/15	81.6 <sup>a</sup>	3.8 <sup>a</sup>	584.4 <sup>a</sup>	2.8 <sup>a</sup>	2.9 <sup>a</sup>	0.9 <sup>b</sup>
15/20/25	82.8 <sup>a</sup>	3.3 <sup>ab</sup>	631.4 <sup>a</sup>	2.7 <sup>ab</sup>	2.2 <sup>b</sup>	1.2 <sup>a</sup>
20	82.4 <sup>a</sup>	3.0 <sup>b</sup>	651.1 <sup>a</sup>	2.3 <sup>b</sup>	2.1 <sup>b</sup>	1.0 <sup>ab</sup>

<sup>1</sup>: Means of treatment effects within columns followed by similar letters are not significantly different at 5%. The same applies to means of temperature effects.  
<sup>2</sup>: Alternating temperatures indicate temperatures on days 1, 2 and 3, respectively and 20°C represents a continuous temperature for the whole 3 d period.  
FGP: Final Germination Percentage, MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle and PRR: Plumule/Radicle Ratio.

not affected by soaking treatments. The sequence of incubation temperature did not play a role in the FGP of seeds, but rather in the MGT (Table 4). Seeds incubated under the 20°C constant temperature regime germinated faster than those incubated under the 25/20/15°C sequence (R1). There was no significant difference between R1, R2 and R3 in GI terms. The growth of plumules and radicles in addition to their ratio was affected by temperature regime, as 25/20/15°C gave significantly higher DWP than both 15/20/25°C and 20°C. The difference in weight between plumules and radicles in favour of the former was more pronounced at 4g l<sup>-1</sup> NaCl in R2 than in R1, thus yielding higher PRR values in the former (Table 5).

The general picture which emerges from the data is that the seed soaking treatments reported seem to be more efficient in increasing germination speed than its final percentage. This effect appears not to be altered by post treatment drying of the seed since the general line of effects observed in the first experiment where seeds were sown fresh was also observed in the dried-back seeds of the second and third experiments. Moreover, the three experiments included different temperature and moisture conditions. The constant temperature experiment was conducted at 35°C without inducing drought, whereas the alternating temperature experiment had a 42/18°C day/night temperature averaging 30°C on a 24 h basis. It also received a PEG-induced drought treatment of -10 bar as did the third experiment. This would tend to point to flexibility in the

**Table 5:** Interactive effects of seed treatments and incubation temperature sequences on germination and seedling characteristics of sorghum SPV 462 seeds.

Seed Treatment	Incubation Temp. (°C) <sup>1</sup>	FGP (%)	MGT (day)	GI	DWP (mg)	DWR (mg)	PPR
Dry Ctrl.	25/20/15	85.3 <sup>b</sup>	4.0 <sup>a</sup>	588.3 <sup>d</sup>	2.8 <sup>a</sup>	2.6 <sup>bc</sup>	1.0 <sup>a-c</sup>
	15/20/25	84.6 <sup>b</sup>	3.9 <sup>a</sup>	598.6 <sup>cd</sup>	2.5 <sup>ab</sup>	2.0 <sup>cd</sup>	1.2 <sup>ab</sup>
	20	82.0 <sup>bc</sup>	3.7 <sup>ab</sup>	593.0 <sup>d</sup>	2.0 <sup>b</sup>	1.8 <sup>d</sup>	1.0 <sup>a-c</sup>
4g NaCl/l	25/20/15	82.3 <sup>bc</sup>	3.6 <sup>ab</sup>	603.0 <sup>cd</sup>	2.8 <sup>a</sup>	3.3 <sup>a</sup>	0.8 <sup>c</sup>
	15/20/25	91.0 <sup>a</sup>	2.8 <sup>cd</sup>	742.3 <sup>a</sup>	3.1 <sup>a</sup>	2.3 <sup>b-d</sup>	1.3 <sup>a</sup>
	20	81.0 <sup>bc</sup>	2.4 <sup>d</sup>	691.3 <sup>ab</sup>	2.1 <sup>b</sup>	2.1 <sup>cd</sup>	0.9 <sup>bc</sup>
4g KCl/l	25/20/15	77.3 <sup>cd</sup>	3.7 <sup>ab</sup>	559.0 <sup>d</sup>	2.8 <sup>a</sup>	2.9 <sup>ab</sup>	1.0 <sup>a-c</sup>
	15/20/25	73.0 <sup>d</sup>	3.3 <sup>a-c</sup>	553.3 <sup>d</sup>	2.5 <sup>ab</sup>	2.5 <sup>b-d</sup>	1.0 <sup>a-c</sup>
	20	84.3 <sup>b</sup>	3.0 <sup>b-d</sup>	669.0 <sup>bc</sup>	3.0 <sup>a</sup>	2.5 <sup>bc</sup>	1.1 <sup>a-c</sup>

Means within columns followed by similar letters are not significantly different at 5%.

<sup>1</sup>: Alternating temperatures indicate temperatures on days 1, 2 and 3, respectively and 20°C represents a continuous temperature for the whole 3 d period.

FGP: Final Germination Percentage, MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle and PPR: Plumule/Radicle Ratio.

response of sorghum and pearl millet seeds to soaking treatments within the range between 27 and 35°C during germination, confirming earlier reports (ZISKA and BUNCE, 1993; FORCELLA *et al.*, 2000; TIRYAKI and ANDREWS, 2001; HARRIS, 2001).

Incubation temperature during treatment, on the other hand, seems to act in another way. A constant temperature during seed soaking appears to be more favourable for post-treatment germination than an alternating regime. In the first experiment, seeds were exposed to constant temperatures ranging from 10 to 35°C. In the second experiment the 25/20, 25/15 °C and 25/10°C regimes gave a 24 h average of 22.5, 20.0 and 17.5°C, respectively. Nevertheless, the average temperature during a day in soaking seems not to be the critical point. More significant appears to be the change in temperature, be it increasing or decreasing, during treatment. This could be confirmed by the data of the third experiment. The 25/20/15 and 20°C regimes all averaged 20°C over the 3 d soaking period. This 20°C given in one constant bulk of heat units (R3), however, yielded better post-treatment results than an increasing (R1) or decreasing (R2) regime. The upper limit of temperature with which one may treat seeds of the genotypes tested is 30°C. Temperatures over 30°C (i.e 35°C in this investigation) yielded poor results. Also, some seeds were observed to germinate during treatment as early as 24 h after initial soaking at 30 and 35°C. This was most severe in pearl millet HHB 67 and less in the M35-1 sorghum variety, and confirms earlier tests (AL-MUDARIS and JUTZI, 1998b,c,a, 1999a,b).

Generally, but not always significantly, a rise in incubation temperature during treatment increased post-treatment germination speed, which agrees with the data of KHAN *et al.* (1980) who obtained higher germination rates at 20°C in comparison to 10 or 15°C. However, no effect on the FGP was detected. The fact that 12 h a day of temperatures 20°C or lower (i.e. 20, 15 and 10°C in the second experiment) during a 24 h cycle,

or for 24 h during a 72 h cycle (R1 and R2 treatments of the third experiment) were not as effective as the constant 20°C may point to an absolute temperature preference by soaked seeds. This means that if a threshold “low” is reached, certain changes may occur within the seed that are dependent on future temperatures in a way that may be similar to certain qualitative light responses in flowering plants. Lima bean (*Phaseolus lunatus* L.) seeds imbibed at 15°C and then allowed to germinate and grow at 25°C have been shown to produce smaller seedlings (POLLOCK and TOOLE, 1966). Thus, sensitivity to chilling injury during the first 10 minutes of imbibition has been proposed (POLLOCK and TOOLE, 1966; KESTER *et al.*, 1997; AL-MUDARIS, 1998b; KOLASINSKA *et al.*, 2000; MASSARDO *et al.*, 2000; GALLARDO *et al.*, 2001; KADER and JUTZI, 2002). HEGARTY (1978) concluded that increased injury during soaking in some species at 10 or 30°C compared to 20°C is associated with greater losses of solutes from the seeds. SIMON and WIEBE (1975), on the other hand, reported that the extent of leakage depends on initial water content of the seeds, being very low if embryos already have a water content of 30% or more ( $\Psi_s$  of -80 bars) before soaking. This would not apply to the seed batches used in these experiments since moisture contents of seeds were within the normal limits of circa 13-15.0 %.

Seeds in experiments 2 and 3 were dried back after treatment and it has been reported that embryos imbibed for 60 minutes, dried and returned to water again show a rapid leakage of solutes (BEWLEY and BLACK, 1978a,b). This may be one of the reasons why dry controls gave higher FGP values in experiment 2. Imbibition at a high temperature of 35°C also increases sensitivity to ethylene (ZARNSTORFF *et al.*, 1994) whilst at 30°C cytokinin passage from the cotyledon to the embryonic axis is affected (ELOISA REVILLA *et al.*, 1988). HASSAN *et al.* (1985) observed decreased auxin concentrations with time in seeds of *Anemone coronaria* and *Ranunculus asiaticus* at 8°C compared with 24°C during soaking. CHEN *et al.* (1983) reported reduced germination of chickpea seeds down to 30% when soaked at 2°C compared to 95% at 20°C. This tends to point to the presence of a threshold minimum and/or maximum below or above which seeds respond through a number of physiological events.

An increase in soaking temperature affected germination speed. This is in agreement with the results of ARGERICH and BRADFORD (1989) and HARDEGREE (1994), who showed increases in germination rate with rises in temperature up to 25°C. HEYDECKER *et al.* (1973) arrived at similar conclusions, and KHAN *et al.* (1978) found that osmo-conditioning celery seeds at 15°C was not as effective as at 20°C in shortening the germination period. Cotton seed germination has been found to be affected by presowing imbibition temperature. MCCARTY (1992), studying cyclic temperature schemes, indicated that imbibing seeds at 10°C resulted in more adverse effects than imbibing at 25°C. Keeping seeds at 10°C for periods greater than 24 h reduced seedling emergence compared with keeping seeds at 10°C for 24 h then increasing substrate temperature. Increasing substrate temperature after 48 h of exposure to 10°C was found not to reverse the damaging effects of low temperatures. This tends to confirm the conclusion that 20 to 25°C is the optimal treatment temperature.

The effect of soaking treatments on the germination and early axis growth of seedlings may not be attributed to the  $\Psi_s$  of solutions, which would decrease water uptake as it drops (GURMU and NAYLOR, 1991), but rather to possible physiological or ionic effects (AL-MUDARIS, 1998b; DEWAR *et al.*, 1998; REN and KERMODE, 1999; RICHARDS *et al.*, 2001; TIRYAKI and ANDREWS, 2001). In experiment 1 the  $5\text{g l}^{-1}$   $\text{KNO}_3$  solution measured  $-2.4$  bar on the osmometer vs.  $-3.9$  bar for  $5\text{g l}^{-1}$   $\text{NaCl}$ . The  $\Psi_s$  of  $4\text{g l}^{-1}$   $\text{NaCl}$  and  $8\text{g l}^{-1}$   $\text{NaCl}$  solutions in the second experiment were  $-3.2$  and  $-5.7$  bar, respectively and that of  $4\text{g l}^{-1}$   $\text{KCl}$  in experiment 3 was  $-2.4$  bar. It follows that differences were not large in the  $\Psi_s$  between treatments and it is, thus, difficult to trace back results to this factor, which would typically arise from notable differences in  $\Psi_s$  (HADAS and RUSSO, 1974).

The greatest increase in germination speed in the constant temperature experiment was in the  $\text{GA}_3$  treatment. The production of gibberellin is speculated to be a prerequisite for radicle emergence (BEWLEY and BLACK, 1978a; WANG *et al.*, 1998; LIN *et al.*, 1998; PEDERSEN and TOY, 2001; LJUNG *et al.*, 2001). Additionally, cell extension of plant tissue is generally held to be regulated by hormones, especially auxins and gibberellins and, since germination culminates in radicle emergence, which in most cases comprises only cell enlargement and not necessarily cell division (BEWLEY and BLACK, 1978a; DOMINGUEZ and CEJUDO, 1999; NASCIMENTO and WEST, 2000; LAHUTA *et al.*, 2000), the promotive role of  $\text{GA}_3$  in increasing germination speed is not surprising. Additionally, on the premise that germination may involve the synthesis of specific proteins/enzymes, the possibility that  $\text{GA}_3$  may have an effect on protein and/or RNA synthesis (BEWLEY and BLACK, 1978b) still remains open. Exogenous application of  $\text{GA}_3$  has been reported to stimulate growth (KOZLOWSKI, 1972) and germination percentages and rates in sorghum seeds soaked for 4-6 days in 500 or 750 ppm  $\text{GA}_3$  at 15 and  $20^\circ\text{C}$  (SANTIPRACHA, 1986).

$\text{KCl}$  was not as effective as  $\text{NaCl}$  since it yielded lower FGPs in the third experiment. The observed difference may lie within the  $\text{K}^+$  and  $\text{Na}^+$  ions since  $\text{Cl}^-$  is common between the two compounds. Potassium is characterized by high mobility in plants at cellular, tissue or long distance transport levels (MARSCHNER, 1995) and seems essential for the synthesis of metabolites (KOZLOWSKI, 1972). Sodium is less essential than  $\text{K}^+$  as a mineral nutrient (MARSCHNER, 1995). The  $4\text{g l}^{-1}$   $\text{KCl}$  and  $4\text{g l}^{-1}$   $\text{NaCl}$  solutions had almost the same pH values of 5.84 and 5.87, respectively, and electrical conductivity values of  $7.35$  and  $6.92$   $\text{mS cm}^{-1}$ , respectively. Thus, other internal effects may have played a role since a relationship between potassium, magnesium and phosphate ions, and gibberellic acid is known to exist (BEWLEY and BLACK, 1978a). Influx of  $\text{Na}^+$ ,  $\text{Cl}^-$  and  $\text{K}^+$  ions into the seed may have altered the response to temperature as these have an impact on physiological triggers (KEIFFER and UNGAR, 1997; GLENN and BROWN, 1998; HOWARD and MENDELSSOHN, 1999; GAXIOLA *et al.*, 2001).

In conclusion it is recommended that ambient room temperatures of  $20$  to  $25^\circ\text{C}$  be used for the soaking treatments reported since gains through alternating temperatures were not observed. It would also be interesting to validate the effect of  $\text{GA}_3$  on sorghum and

millet seeds under other conditions and to further investigate the effects of Na<sup>+</sup> and K<sup>+</sup> in seed priming treatments.

## References

- AL-MUDARIS, M.; Notes on various parameters recording the speed of seed germination; *Journal of Agriculture in the Tropics and Subtropics*; 99(2):147–154; 1998a.
- AL-MUDARIS, M.; *Studies on osmotic conditioning seed treatments to enhance germination and early seedling growth of sorghum and pearl millet under drought, heat and combined stress conditions*; Tectum Verlag Publishers, Marburg, Germany, 225pp.; 1998b.
- AL-MUDARIS, M. and JUTZI, S.; The effect of incubation temperature during presowing seed treatments on the subsequent germination behavior in Sorghum bicolor and Pennisetum glaucum; *German Journal of Agronomy*; 2:131–134; 1998a.
- AL-MUDARIS, M. and JUTZI, S.; Emergence and growth characteristics of sorghum and pearl millet intercropped with French beans after PEG-based seed priming under greenhouse and phytotron conditions; *Journal of Agriculture in the Tropics and Subtropics*; 99(1):31–42; 1998b.
- AL-MUDARIS, M. and JUTZI, S.; The influence of genotype, priming material, temperature and osmotic potential of priming solution on imbibition and subsequent germination of sorghum and pearl millet seeds during and after treatment; *Journal of Agriculture in the Tropics and Subtropics*; 99(2):133–145; 1998c.
- AL-MUDARIS, M. and JUTZI, S.; The influence of fertilizer-based seed priming treatments on emergence and seedling growth of Sorghum bicolor and Pennisetum glaucum in pot trials under greenhouse conditions; *Journal of Agronomy and Crop Science*; 182:135–142; 1999a.
- AL-MUDARIS, M. and JUTZI, S.; Osmotically primed seed and seedling reactions to variations in day/night temperature; *Journal of Agronomy and Crop Science*; 182:217–221; 1999b.
- ARAUS, J., SLAFER, G., REYNOLDS, M. and ROYO, C.; Plant breeding and drought in C<sub>3</sub> cereals: what should we breed for?; *Annals of Botany*; 89:925–940; 2002.
- ARGERICH, C. and BRADFORD, K.; The effects of priming and ageing on seed vigour in tomato; *Journal of Experimental Botany*; 40:599–607; 1989.
- AUSTIN, R., LONGDEN, P. and HUTCHINSON, J.; Some effects of “Hardening” carrot seed; *Annals of Botany*; 33:883–895; 1969.
- BARRILLEAUX, T. and GRACE, J.; Growth and invasive potential of *Sapium sebiferum* (Euphorbiaceae) within the coastal prairie region: The effects of soil and moisture regime; *American Journal of Botany*; 87:1099–1106; 2000.
- BENECH ARNOLD, R. L., FENNER, M. and EDWARDS, P.; Changes in germinability, ABA content and ABA embryonic sensitivity in developing seeds of Sorghum bicolor (L.) Moench induced by water stress during grain filling; *New Phytologist*; 118:339–347; 1991.
- BEWLEY, J. and BLACK, M.; *Physiology and Biochemistry of Seeds*; vol. 1; Heidelberg, Springer-Verlag; 1978a.



- BEWLEY, J. and BLACK, M.; *Physiology and Biochemistry of Seeds*; vol. 2; Heidelberg, Springer-Verlag; 1978b.
- BOOTH, D.; Seedbed ecology of winterfat: imbibition temperature affects post-germination growth; *Journal of Range Management*; 45:159–164; 1992.
- BROCKLEHURST, P. A. and DEARMAN, J.; A comparison of different chemicals for osmotic treatment of vegetable seed; *Annals of Applied Biology*; 105:391–398; 1984.
- CHEN, T., YAMAMOTO, S., GUSTA, L. and SLINKARD, A.; Imbibitional chilling injury during chickpea germination; *Journal of the American Society for Horticultural Science*; 108:944–948; 1983.
- DEMIR, I. and VAN DE VENTER, H.; The effect of priming treatments on the performance of watermelon (*Citrullus lantus* (Thunb.) Matsum & Nakai) seeds under temperature and osmotic stress; *Seed Science and Technology*; 27:871–876; 1999.
- DEWAR, J., TAYLOR, J. and BERJAK, P.; Changes in selected plant growth regulators during germination in sorghum; *Seed Science Research*; 8:1–8; 1998.
- DOMINGUEZ, F. and CEJUDO, F.; Patterns of starchy endosperm acidification and protease gene expression in wheat grains following germination; *Plant Physiology*; 119:81–88; 1999.
- ELOISA REVILLA, M., MARTIN, L., NICOLAS, G., ESTRELLA LEGAZ, M. and VILLALOBOS, N.; Effects of high temperature on the variation and transport of endogenous cytokinins during the germination of chickpea seeds; *Journal of Plant Physiology*; 132:223–228; 1988.
- FORCELLA, F., BENECH ARNOLD, R., SANCHEZ, R. and GHERSA, C.; Modeling seedling emergence; *Field Crops Research*; 67:123–139; 2000.
- GALLARDO, K., JOB, C., GROOT, S., PUYPE, M., DEMOL, H., VAN DE KERCHHOVE, J. and JOB, D.; Proteomic analysis of Arabidopsis seed germination and priming; *Plant Physiology*; 120:835–848; 2001.
- GAXIOLA, R., LI, J., UNDURRAGA, S., DANG, L., ALLEN, G., ALPER, S. and FINK, G.; Drought- and salt-tolerant plants result from over-expression of the AVP1H<sup>+</sup>-pump; *American Journal of Botany*; 98:1444–1449; 2001.
- GEORGHIOU, K., THOMAS, C. and PASSAM, H.; Osmoconditioning as a means of counteracting the ageing of pepper seeds during high temperature storage; *Annals of Botany*; 60:279–285; 1987.
- GLENN, E. and BROWN, J.; Effects of soil salt levels on the growth and water use efficiency of *Atriplex canescens* (Chenopodiaceae) varieties in drying soil; *American Journal of Botany*; 85:10–11; 1998.
- GOSLING, P., PARRATT, M. and PEACE, A.; Identifying the optimum pretreatment duration and germination temperature; *Seed Science and Technology*; 27:951–962; 1999.
- GURMU, M. and NAYLOR, R.; Effects of low water availability on germination of two Sorghum cultivars; *Seed Science and Technology*; 19:373–383; 1991.
- GURUSHINGHE, S., CHENG, Z. and BRADFORD, K.; Cell cycle activity during seed priming is not essential for germination advancement in tomato; *Journal of Experimental Botany*; 50:101–106; 1999.

- HADAS, A. and RUSSO, D.; Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil water contact, 1. Experimental study; *Agronomy Journal*; 66:643–647; 1974.
- HAMPTON, J., COOKSON, W., GRAMA, A., ROWARTH, J., MC GILL, C., HILL, M. and CAMERON, K.; Temperature and time variables for accelerated ageing testing of perennial ryegrass (*Lolium perenne* L.) seed lots; *Seed Science and Technology*; 28:861–863; 2000.
- HARDEGREE, S.; Matric priming increases germination rate of great basin native perennial grasses; *Agronomy Journal*; 86:289–293; 1994.
- HARRIS, D.; The effects of manure, genotype, seed priming, depth and date of sowing on the emergence and early growth of *Sorghum bicolor* (L.) Moench in semi-arid Botswana; *Agricultural Systems*; 70:335–350; 2001.
- HASSAN, H., AGINA, E., I., B. and MOHAMED, S.; Some physiological studies on seed germination of some ornamental plants; *Annals of Agricultural Science*; 22:617–630; 1985.
- HEGARTY, T.; The physiology of seed hydration and dehydration, and the relation between water stress and the control of germination: a review; *Plant, Cell and Environment*; 1:101–119; 1978.
- HEYDECKER, W.; “Primed” seeds for better crop establishment?; *Span*; 21:12–14; 1978.
- HEYDECKER, W. and GIBBINS, B.; The “priming” of seeds; *Acta Horticulturae*; 83:213–215; 1978.
- HEYDECKER, W., HIGGINS, J. and GULLIVER, R.; Accelerated germination by osmotic seed treatment; *Nature*; 246:42–44; 1973.
- HOULE, G., MOREL, L., REYNOLDS, C. and SIEGEL, J.; The effect of salinity on different developmental stages of an endemic annual plant, *Aster laurentians* (Asteraceae); *American Journal of Botany*; 88:62–67; 2001.
- HOWARD, R. and MENDELSSOHN, I.; Salinity as a constraint on growth of oligohaline marsh macrophytes. II. Salt pulses and recovery potential; *American Journal of Botany*; 86:795–806; 1999.
- IANNUCCI, A., DI FONZO, N. and MARTINIELLO, P.; Temperature requirements for seed germination in four annual clovers grown under two irrigation treatments; *Seed Science and Technology*; 28:59–66; 00.
- ISTA; *International Rules for Seed Testing*; vol. 21 of *Seed Science and Technology, Supplement*; International Seed Testing Association; 1993.
- KADER, M.; Heat shock events, inhibition of seed germination and the role of growth regulators in stress alleviation; *Journal of the Royal Society of New South Wales*; 134:79–88; 2001.
- KADER, M. and JUTZI, S.; Drought, heat and combined stresses and the associated germination of two sorghum varieties osmotically primed with NaCl; *Phytogen*; 3:22–24; 2001.
- KADER, M. and JUTZI, S.; Temperature, osmotic pressure and seed treatments influence imbibition rates in sorghum seeds; *Journal of Agronomy and Crop Science*; 188:1–5; 2002.

- KEIFFER, C. and UNGAR, I.; The effect of extended exposure to hypersaline conditions on the germination of five inland halophyte species; *American Journal of Botany*; 84:104–105; 1997.
- KESTER, S. T., GENEVE, R. L. and HOUTZ, R.; Priming and accelerated ageing affect L-isoaspartyl methyltransferase activity in tomato (*Lycopersicon esculentum* Mill.) seed; *Journal of Experimental Botany*; 48:943–949; 1997.
- KHAN, A., KAR-LING, T., KNYPL, J. and BORKOWSKA, B.; Osmotic conditioning of seeds: Physiological and biochemical changes; *Acta Horticulturae*; 83:267–278; 1978.
- KHAN, A., PECK, N. and SAMIMY, C.; Seed osmoconditioning: Physiological and biochemical changes; *Israel Journal of Botany*; 29:133–144; 1980.
- KOLASINSKA, K., SZYRMER, J. and DUL, S.; Relationship between laboratory seed quality tests and field emergence of common bean seed; *Crop Science*; 40:470–475; 2000.
- KOZLOWSKI, T.; *Seed Biology*; vol. 2; Academic Press, New York; 1972.
- LAHUTA, L., YOGIN, A., REJOWSKIL, A., SOCHA, A. and ZALEWSKI, K.; Influence of water deficit on the accumulation of sugars in developing field bean (*Vicia faba* var minor) seeds; *Seed Science and Technology*; 28:93–100; 2000.
- LIN, J. and SUNG, J.; Pre-sowing treatments for improving emergence of bitter melon seedlings under sub-optimal temperatures; *Seed Science and Technology*; 29:39–50; 2001.
- LIN, T., YEN, W. and CHIEN, C.; Disappearance of desiccation tolerance of imbibed crop seeds is not associated with the decline of oligosaccharides; *Journal of Experimental Botany*; 49:1203–1212; 1998.
- LJUNG, K., OSTIN, A., LIOUSSANNE, L. and SANDBERG, G.; Developmental regulation of indole-3-acetic acid turnover in scots pine seedlings; *Plant Physiology*; 125:464–475; 2001.
- MARSCHNER, H.; *Mineral Nutrition of Higher Plants. Second Edition*; Academic Press, London; 1995.
- MASSARDO, F., CORCUERA, L. and ALBERDI, M.; Embryo physiological responses to cold by two cultivars of aot during germination; *Crop Science*; 40:1694–1701; 2000.
- MCCARTY, W.; Germination and emergence of cotton seed as affected by seed quality, substrate temperature and subsequent moisture content; *Dissertation Abstracts International, B. Sciences and Engineering*; 52:3351; 1992.
- NASCIMENTO, W. and WEST, S.; Drying during muskmelon (*Cucumis melo* L.) seed priming and its effects on seed germination and deterioration; *Seed Science and Technology*; 28:211–215; 2000.
- ORCHARD, T.; Estimating the parameters of plant seedling emergence; *Seed Science and Technology*; 5:61–69; 1977.
- PEDERSEN, J. F. and TOY, J. J.; Germination, emergence, and yield of 20 plant-color, seed-color near isogenic lines of grain sorghum; *Crop Science*; 41:107–110; 2001.
- POLLOCK, B. M. and TOOLE, V. K.; Imbibition period as the critical temperature sensitive stage in germination of Lima bean seeds; *Plant Physiology*; 41:221–229; 1966.

- POWELL, A., YULE, L., JING, H., GROOT, S., BINO, R. and PRITCHARD, H.; The influence of aerated hydration seed treatment on seed longevity as assessed by the viability equations; *Journal of Experimental Botany*; 51:2031–2043; 2000.
- PRITCHARD, H., STEADMAN, K., NASH, J. and JONES, C.; Kinetics of dormancy release and the high temperature germination response in *Aesculus hippocastanum* seeds; *Journal of Experimental Botany*; 50:1507–1514; 1999.
- REN, C. and KERMODE, A.; Analyses to determine the role of the megagametophyte and other seed tissues in dormancy maintenance of yellow cedar (*Chamaecyparis nootkatensis*) seeds; morphological, cellular and physiological changes following moist chilling and during germination; *Journal of Experimental Botany*; 50:1403–1419; 1999.
- RENNICK, G. and TIERNAN, P.; Some effects of osmopriming on germination, growth and yield of celery (*Apium graveolens*); *Seed Science and Technology*; 6:695–700; 1978.
- RICHARDS, D., KING, K., AITALI, T. and HARBERD, N.; How gibberellin regulates plant growth and development: a molecular genetic analysis of gibberellin signaling; *Annual Review of Plant Physiology and Plant Molecular Biology*; 52:67–88; 2001.
- SALISBURY, F. and ROSS, C.; *Plant Physiology*; Wadsworth, Belmont, CA, USA; 1992.
- SANTIPRACHA, Q.; Improvement of sorghum seed germination and emergence under stress conditions by seed treatments; *Dissertation Abstracts International, B. Sciences and Engineering*; 47:862; 1986.
- SAS; *SAS user's guide, version 6*; SAS Institute, Cary, North Carolina, USA; 1989.
- SIMON, E. and WIEBE, H.; Leakage during imbibition, resistance to damage at low temperature and the water content of peas; *New Phytologist*; 74:407–411; 1975.
- STEINMAUS, S., PRATHER, T. and HOLT, J.; Estimation of base temperatures for nine weed species; *Journal of Experimental Botany*; 51:275–286; 2000.
- SWAGEL, E., BERNHARD, A. and ELLMORE, G.; Substrate water potential constraints on germination of the strangler fig *Ficus aurea* (Moraceae); *American Journal of Botany*; 84:716–722; 1997.
- TIRYAKI, I. and ANDREWS, D.; Germination and seedling cold tolerance in sorghum; *Crop Science*; 42:1391–1397; 2001.
- WANG, M., VAN DER MEULEN, R., VISSER, K., VAN SCHAIK, H., VAN DUJN, B. and DE BOER, H.; Effects of dormancy-breaking chemicals on ABA levels in barley grain embryos; *Seed Science Research*; 8:129–137; 1998.
- WEBER, E. and ANTONIO, C.; Germination and growth responses of hybridising *Carporotus* species (Aizoaceae) from coastal California to soil salinity; *American Journal of Botany*; 86:1257–1263; 1999.
- WELBAUM, G., BRADFORD, K., YIM, K., BOOTH, D. and OLUOCH, M.; Biophysical, physiological and biochemical processes regulating seed germination; *Seed Science Research*; 8:161–172; 1998.
- WUEBKER, E., MULLEN, R. and KOEHLER, K.; Flooding and temperature effects on soybean germination; *Crop Science*; 41:1857–1861; 2001.
- YANG, J., LOVETT-DOUST, J. and LOVETT-DOUST, L.; Seed germination patterns in green dragon (*Arisaema dracontium*, Araceae); *American Journal of Botany*;

86:1160–1167; 1999.

ZARNSTORFF, M., KEYS, R. and CHAMBLEE, D.; Growth regulator and seed storage effects on switchgrass germination; *Agronomy Journal*; 86:667–672; 1994.

ZISKA, L. H. and BUNCE, J. A.; The influence of elevated CO<sub>2</sub> and temperature on seed germination and soil emergence; *Field Crops Research*; 34:147–157; 1993.



## Estimation of Erosion Danger Lands of the Reclamation Fund in Georgia

G. P. Gogichaishvili<sup>\*1</sup> and T. T. Urushadze<sup>2</sup>

### Abstract

Erosion danger of lands of the reclamation fund in Georgia was studied by means of the Universal Soil Loss Equation (USLE) (WISCHMEIER and SMITH, 1978), which was modified in the Problem Lab of Soil Erosion and River Bed Processes of Moscow State University (ANONYMOUS, 1982). By the investigation was established that average annual potential soil loss, which was counted by means of USLE, is 10,5 % less than real loss of soil. If for the calculation of the potential soil loss we use only rains which provoke soil erosion, the difference between real and counted soil losses is only 1.77 % i.e. exactness of soil erosion forecast increases 5-6 times.

**Keywords:** Georgia, erosion danger, lands of Georgia, erosion forecast, USLE

### 1 Introduction

The climate of of Western Georgia is humid subtropical and that of Eastern Georgia arid subtropical. In the hilly regions of Western Georgia only 0,3-1,5 % of the territory are occupied by arable lands and eroded area is decreased to 30-60 %. Lands of reclamation fund of Georgia include most part of the arable lands.

Georgia is a mountainous country, 70 % of its territory is occupied by mountains. Western and Eastern Georgia is divided by the Ajara-Imereti (Likhi) range which is also watershed of the Black and Caspian Sea basin. There is an elevation of southern Georgia. Eastern Georgia includes volcanic upland (volcanic plateau, with neighboring volcanic ranges) and the hollow of Akhaltsikhi.

As the country is mountainous, it's climate, soils and vegetation changes by the vertical zonality.

By the hydrological investigation it was identified that in Georgia average soil loss is 15-20 tons per hectare. Out of 25 % of total area of the river basin soil losses exceeded 30 t/ha per year (Table 1).

The amount of soil losses from the river basins objectively does not reflect heavy erosion danger on the territory of Georgia. Here, water (rain) erosion and irrigation of erosion on the agricultural lands can be observed, because only 15-20 % of washed out soils are

---

\* corresponding author

<sup>1</sup> State Department of Hydrometeorology of Georgia, Tbilisi

<sup>2</sup> Georgian State Agrarian University, Tbilisi

**Table 1:** Annual soil loss by the erosion in the river basins of Georgia

Soil loss (t/ha)	Area of the river basins (km <sup>2</sup> )	
	Western Georgia	Eastern Georgia
< 5	–	4,217
5 - 10	5,118	10,803
10 - 15	–	–
15 - 20	5,900	4,980
20 - 30	17,060	4,351
> 30	6,484	10,987

going into a river (BROWN, 1984; KOKOREVA, 1985). In mountainous regions of the Western Georgia, arable lands occupy only 0,3-1,5 % of the total area. Among them, 80 - 90 % are eroded. In Eastern Georgia area of arable lands increases up to 5-15 % and area of eroded soils decreases from 30 to 60 %.

Considering the above represented facts, it is clear, that studying soil erosion processes and its cartography is inevitable for Georgia. Research and cartography of study results in this field have not yet been conducted in Georgia.

## 2 Objectives and Methods

Erosion danger of lands was studied by means of the Universal soil Loss Equation (USLE) (WISCHMEIER and SMITH, 1978):

$$A = R * K * S * L * C * P \quad (1)$$

where:

$A$  is the soil loss in t/ha;

$R$  is the rainfall erosivity index (MJ\*mm/ha\*min\*year);

$K$  is the soil erodibility factor (t\*ha\*min/ha\*MJ\*mm);

$S$  and  $L$  are the dimensionless topographical slope and length factors;

$C$  - the dimensionless cover of soil surface and management factor;

$P$  - the dimensionless specific erosion control practices factor.

The rainfall factor was calculated by the equation of ZASLAVSKI *et al.* (1981):

$$R_{30} = 0,25841 * H * I_{30} - 0.14921 \quad (2)$$

where:

$R_{30}$  is the rainfall factor (MJ mm/ha min year);

$H$  is the amount of rain (mm);

$I_{30}$  is the 30min maximum intensity of rain (mm/min)

By definition, the  $K$  factor is the average amount of soil eroded annually from a standard fallow plot (which is of 22.1 m (72.6 f) length on a uniform slope of 9 %, in continuous



fallow and tilled up and down the slope) per unit of erosion index ( $R$ ). This factor was determined using the nomogram and formula of WISCHMEIER and SMITH (1978); WISCHMEIER *et al.* (1971):

$$K = \sum A/R \quad (3)$$

The  $K$  or soil erodibility factor is based on six factors: % clay, % silt plus very fine sand, % organic matter, coarse fragment content, permeability and structure (WISCHMEIER and SMITH, 1978).

For estimation of LS-length and steepness factor, on the lands of reclamation fund of Georgia, which contains the most part of arable lands, division into districts was carried out on the map of 1 : 500 000 scale (LITVIN and MIRGORODSKAIA, 1976), the reason of geomorphologic division is separation resembling type of relief. Non-erosion danger area – lowland bog soil area, wide plains saline soils and solonchaks and also sands were separated on the map. On the cartographic net for each geomorphological district, the topographical maps were selected 1 : 25 000 scale.

Quantity of maps depends on the area of region dismember of relief. In general, it is desirable for plane regions to take not less than 10 sheets of topographical maps, but foothills, uplands and mountainous region not less than 20 sheets. On the selected sheets of topographical maps, length and inclination of slopes are measured by the point-statistical method (ANONYMOUS, 1982; LITVIN and MIRGORODSKAIA, 1976; LITVIN, 1976). By the above mentioned method of separated points, a big amount of measuring on the map gives an objective characteristic of its average meaning. On each kind of arable land of the geomorphologic district compartment of measurements for various arable lands will be different. If arable land is surplus (70-80 %), then it is quite enough to measure at the knot of the coordinate net. On hay mowing and pasture lands, length and inclination must be measured separately from each other by 1, 1.5, 2 and i.e. cm., points to collect quite enough amount of measurements. In local agricultural regions conversely, it is inevitable to condense the measured net on the arable land.

In the chosen points for measurements, there must be drawn line till watershed beyond the man-made border – such as line of protective afforestation, profile of roads or border of arable land (field, pasture) and down, also till the arable lands or above mentioned man-made border, ravine thalweg. Below, in case of sharply straighten, line of flow is finishing at the section of slope sag (straighten) (ANONYMOUS, 1982).

Therefore, in the arable land already we have length (m) and inclination (%) by geomorphologic region. Next stage is calculation of erosion index of relief by the following equation according to WISCHMEIER and SMITH (1978)

$$LS = \left( \frac{X}{22.13} \right)^m (0.065 + 0.45S + 0.0065S^2) \quad (4)$$

where:

$LS$  is the dimensionless factor of the relief

$S$  - inclination of the slope (in %);

$X$  - length of the slope (in m);

$m$  - index of degree.

WISCHMEIER and SMITH (1978) gave the following  $m$ -index of degrees:

$m = 0.5$  - if inclination of slope is  $> 5$  %;

$m = 0.4$  - if inclination is  $\leq 5$  and  $> 3$  %;

$m = 0.3$  - if inclination is  $\leq 3$  and  $\geq 1$  %;

$m = 0.2$  - if inclination is  $< 1$  %.

After finishing of the morphological works, for each region will be drawn up diagram of erosion index of relief, with fixed interval, which for arable land is 0.25 and pasture - 1.0. Because, on the last classes fit small amount of measured parameter, therefore, we are correcting the left side of the diagram.

To compare the neighbor regions to each other, to determine true difference according the distribution of erosion potential of relief, criterion of Kolmogorov has been used (ANONYMOUS, 1982)

$$\lambda = \left( \frac{\sum n_1}{N_1} - \frac{\sum n_2}{N_2} \right) \sqrt{\frac{N_1 * N_2}{N_1 + N_2}} \quad (5)$$

where:

$\sum n_1/N_1$  and  $\sum n_2/N_2$  are accumulated frequencies (measurement) sum for each class, divided by the total amount of data of the first and second distribution (for the comparable regions).

If  $\lambda \geq 1.36$ , difference among the regions is true.

Then the area of arable land and pasture will be calculated, in % by classes the erosion index relief. Area of  $P$  class lands is  $S_p$ , and calculated by the following equation,

$$S_p = \frac{n_p}{N} * 100\% \quad (6)$$

where:

$n_p$  is the number of measurements by  $P$  class of the relief erosion index;

$N$  is the total amount of measurements in geomorphological region on the arable lands and pasture.

Results are written in the table of the land distribution by geomorphological region.

For the calculation plant cover and management factor it is possible use method of USLE (WISCHMEIER and SMITH, 1978), but for large and small scale investigation it was calculated by the equivalent soil protection plant group.

All plants were divided the following groups:

- 1) Winter crop (wheat, barley, oats and etc.);
- 2) Spring crop, with height stalk hoe (maize, sunflower);
- 3) Low stalk hoe (sugar beet, folder root crops, melons, potato, tobacco);
- 4) Perennial grasses.

Besides, the separate area of the fallow is taken into account. These groups are divided by methods of soil till and agrotechnics:

- a) Turn over a clod (traditional agrotechnique);
- b) Cultivation with subsurface cultivator;
- c) Industrial technology.

Total soils protection coefficient by agricultural plant group were calculated from the equation:

$$C = (C_1R_1 + C_2R_2 + \dots + C_nR_n) * 100 \quad (7)$$

where:

$C$  is the soil protection coefficient of the agricultural plants group;

$C_1, C_2, \dots, C_n$  is the soil protection coefficient of the agricultural plants group in different periods, when soil protection of the plants didn't change;

$R_1, R_2, \dots, R_n$  - is amount of erosion index of rain in % per relevant period. Finally, soil protection cartogram composed for investigation region or country.

It's advisable to separate regions from each other with 0.05 stages. Dimensionless erosion control factor ( $P$ ) wasn't used.

Qualitative deflation and irrigation erosion danger of the reclamation fund lands of Georgia studied by the method of Moscow State University Problem Lab of Soil Erosion and Riverbed Processes (ANONYMOUS, 1982).

### 3 Results and Analysis

For assessment of danger and cartography of lands of reclamation fund of Georgia, the Universal Soil Loss Equation (USLE) (WISCHMEIER and SMITH, 1978) and the Hydromechanical Model of Soil Erosion (MIRTSKHOULAVA, 1978) were chosen. The Hydromechanical model of water erosion prognosis and USLE from the physical point of view are different from each other.

The model of Ts. Mirtskhoulava (MIRTSKHOULAVA, 1978) is physically well grounded, but the map-making of territory by the USLE (WISCHMEIER and SMITH, 1978) is relatively easy. The USLE is based on the experimental results of the soil erosion plots data. It's provided with corresponding coefficient of plants and agricultural management. By that USLE stands out from the other methods, because its practical use is easier.

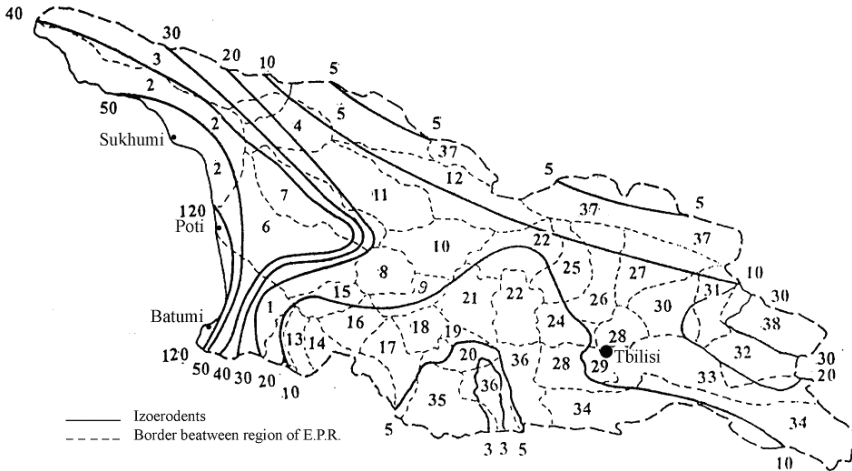
By investigations it was identified that erosion index of the rain ( $R_{30}$ ) is directly proportional to soil loss (WISCHMEIER and SMITH, 1978). Soil losses were calculated by the MIRTSKHOULAVA (1978) model for each rain and erosion index of rain by the USLE. For investigation was taken environs of Akhaltsikhe, in southern Georgia. Length of slope was 150 m, inclination - 11 %. 21 years data of rainfall was used. Correlation coefficient between erosion index of rain and soil loss is 0.959; coefficient of determination is 0.920.

Carrying out tests (9 years) within the mountainous Adjara area, provide that annual potential soil loss calculated by the USLE is 10.5 % less than factual soil loss, relatively. But if soil loss is calculated only by foreseen of rains, which had washed out the soils. Difference between factual and calculated amount of soil losses is 1.77 %, because of the exactness of prognoses (forecast) increases 5-6 times (GOGICHAISHVILI *et al.*, 2003).

The above mentioned research was carried out for estimation erosion danger lands of reclamation fund of Georgia by the USLE (WISCHMEIER and SMITH, 1978).

On the basis of the data of all meteorological stations of Georgia, from 1936 to 1990 average annual erosion index of rain was calculated and the map of Georgia was composed (Fig. 1) (GOGICHAISH VILI and GORJOMELADZE, 1998).

**Figure 1:** Average annual erosion index of rain of Georgia.



On the second stage, on the basis of geomorphological division into districts (GOGICHAISH VILI and GORJOMELADZE, 1998) in the separate geomorphological region on the arable lands, perennial plantation, haymaking and pasture length and inclination of slope were measured according to the point-statistical method (LITVIN and MIRGORODSKAIA, 1976; LITVIN, 1976). After that, for different area the erosion index of relief (LS) was counted (WISCHMEIER and SMITH, 1978).

Geomorphological regions were divided by Kolmogorov criterion (ANONYMOUS, 1982). As for high erosion danger of the lands of the reclamation fund of Georgia indicated that from the separated 20 regions and subregions, in 13, 20-55 % of arable lands were arranged on the slopes with erosion index of relief (LS) which ranges from 5 to 10 unit.

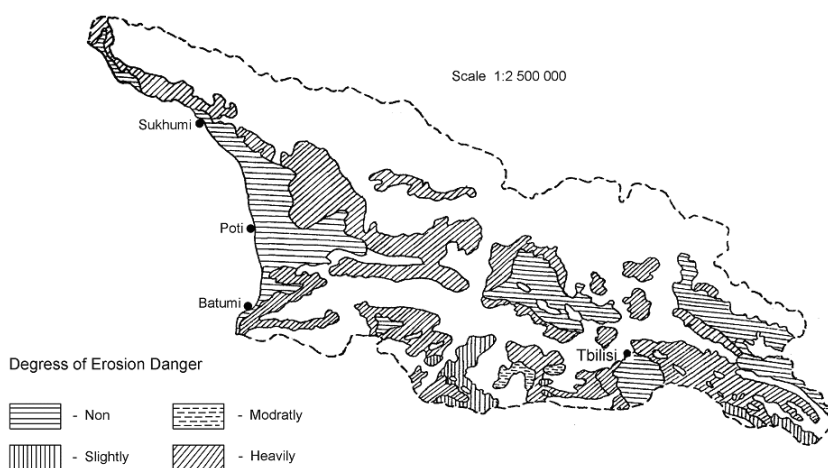
On the third stage, according to the private and fund materials erodibility of top layer soils of Georgia (K-factor) was determined which range from 0.8 to 3.8 t/ha (GOGICHAISHVILI and URUSHADZE, 2000).

In the next stage for 69 regions of Georgia their plant and agricultural management factor (C - factor) was calculated for winter and spring crop, maize, sunflower, potato, sugar beet, tobacco and perennial plantation. It was identified by investigations that in the most part of Georgia factor C varies from 0.419 to 0.661 (GOGICHAISH VILI and GORJOMELADZE, 1998). Based on above mentioned data and the USLE (WISCHMEIER and SMITH, 1978) for the lands of reclamation fund of Georgia annual soil loss was calculated.

Lands and territories where combination of natural conditions is producing possibility of prompt erosion in condition of economic use without methods of erosion control use (ZASLAVSKI, 1979). Soil tolerance was acceptance 2.5 t/ha per year and such territories are considered as non erosion danger lands or weak erosion danger, where potential soil loss is from 2.5 to 5.0 t/ha/year. Lands are of medium erosion danger when potential loss from this land is 5.0-10 t/ha/year and lands are heavy erosion danger where potential soil loss is more than 10 t/ha/year.

Potential soil loss for lands of reclamation fund of Georgia was calculated and composed a map in 1:500,000 scale (Fig.2).

**Figure 2:** Potential soil loss for lands of reclamation fund of Georgia.



Investigations ascertained that out of 103 thousand ha of Autonomous Republic of Abkhazia, 10 thousand ha (10 %) is of weak erosion danger (Table 2). Out of 50 thousand ha of the reclamation fund of A.R. of Adjara 41 thousands ha (82 %) are in condition of erosion danger. Among them 5 thousand ha (13 %) are weak erosion danger, 10 thousand ha medium and 26 thousand ha (63 %) heavy erosion danger. In South Osetia Autonomous District, out of the 64 thousand ha lands of the reclamation fund, 40 thousand ha (62.5 %) is in erosion danger condition. Among them 13 thousand ha (32 %) is weak erosion danger, 8 thousand ha (20 %) - medium and 19 thousand ha (48 %) - heavy erosion danger.

In Georgia, of 304 thousand ha (19 %) of the erosion danger lands of the reclamation fund, (19 %) is weak erosion danger, 80 thousand ha (5 %) - medium and 1194 thousand ha (76 %) - heavy erosion danger. Also 12 thousand ha of irrigated lands are erosion danger.

**Table 2:** Potential erosion and deflation danger of the agricultural and reclamation fund lands.

Administrative regions	Lands of the potential danger of erosion (thousand ha / %)									
	Agricultural lands					Lands of reclamation fund				
	total	among them			total	among them				
		arable lands	mowing and pasture			weak	middle	heavy	irrigation lands	
Eastern Georgia	1070	283	787	964	276	42	646	12		
	100	26	74	100	29	4	67	-		
Western Georgia	500	425	75	430	-	-	430	-		
	100	85	15	100	-	-	100	-		
Regions without autonomous republics	1570	708	862	1394	276	42	1076	12		
	100	45	55	100	20	3	77	-		
Abkhazian A.R.	150	130	20	103	10	20	73	-		
	100	87	13	100	10	19	71	-		
Adjaria A.R.	50	45	5	41	5	10	26	-		
	100	90	10	100	13	24	63	-		
South-Osetia A. Region	64	34	30	4	13	8	19	-		
	100	95	5	100	32	20	48	-		
Total of regions of the Eastern Georgia	1134	317	817	1004	289	50	665	12		
	100	28	72	100	29	5	66	-		
Total of regions of the Western Georgia	700	600	100	574	15	30	529	-		
	100	86	14	100	3	5	92	-		
Total	1834	917	917	1578	304	80	1194	12		
	100	50	50	100	19	5	76	-		

Administrative regions	Potential danger of deflation								Potential danger of irrigation			
	Agricultural lands				Lands of reclamation fund				Lands of reclamation fund			
	total	among them			total	among them			total	among them		
		arable lands	mowing and pasture			weak	middle	heavy		weak	middle	heavy
Eastern Georgia	585	193	392	505	216	223	66	137	128	9	-	
	100	33	67	100	43	44	13	100	93	7	-	
Western Georgia	-	-	-	-	-	-	-	33	26	7	-	
	-	-	-	-	-	-	-	100	79	21	-	
Regions without autonomous republics	585	193	392	505	216	223	66	170	154	16	-	
	100	33	67	100	43	44	13	100	91	9	-	
Abkhazian A.R.	7	-	7	-	-	-	-	10	10	-	-	
	100	-	100	-	-	-	-	100	100	-	-	
Adjaria A.R.	2	-	2	-	-	-	-	4	3	1	-	
	100	-	100	-	-	-	-	100	75	25	-	
South-Osetia A. Region	15	7	8	5	4	1	-	-	-	-	-	
	100	-	-	100	80	20	-	-	-	-	-	
Total of regions of the Eastern Georgia	600	200	400	510	220	224	66	137	128	9	-	
	100	-	-	100	43	44	13	100	93	7	-	
Total of regions of the Western Georgia	9	-	9	-	-	-	-	47	39	8	-	
	100	-	100	-	-	-	-	100	83	17	-	
Total	609	200	409	510	220	224	66	184	167	17	-	
	100	33	67	100	43	44	13	100	91	9	-	

510 thousand ha of the reclamation fund are deflation danger. Among them 220 thousand ha ( 43 %) is concern to weakly deflation danger (Table 2), 224 thousand (44 %) - middle and 66 thousand (13 %) - heavy deflation.

As deflation danger is determined only by the deflation index of the wind, above mentioned estimation is qualitative and approximate (ANONYMOUS, 1982). Estimation of erosion danger of irrigation land is based on the quantitative forecast method.

In western Georgia out of 137 thousand ha lands of reclamation fund, 128 thousand ha (93 %) is weak erosion danger and 8 thousand ha (17 %) - medium erosion danger. Using the of above mentioned method, heavy erosion danger area was not observed.

According to the separate regions of Georgia, in case of producing the traditional agricultural crops and having carried out the erosion processes, the use of the USLE gives an opportunity to control ecological condition on the agricultural lands of reclamation fund of Georgia.

## References

- ANONYMOUS; Methodical instruction for determination of reclamation fund. Section: Erosion-Deflation Ground. Scheme of development reclamation and winter economy of SU for period to 2000 year; Moscow State University; 1982; Russian.
- BROWN, L. R.; The global loss of topsoil; *J. Soil and Water Conservation*; 39(3):165–165; 1984.
- GOGICHAISHVILI, G. P. and URUSHADZE, T. T.; Some Data on Georgian Soils Stability Against Erosion; *Bull. Of the Georgian Academy of Sciences*; 161(2):235–237; 2000.
- GOGICHAISHVILI, G. P., URUSHADZE, T. T. and GORDJOMELADZE, O. L.; Universal soil loss equation for application in Georgia; *J. Pochvovedenie*; 3:240–243; 2003; (Russian).
- KOKOREVA, M. L.; Erosion processes in the eastern and southeastern localities near Moscow; In coll. Study of natural condition and its applied aspects, Moscow, pp. 62-66; 1985; (Russian).
- LITVIN, L. F.; Estimation of relief of medium and small scale draw a map of erosion danger of lands; In coll. Regularity exposure erosion and riverbed processes in different natural condition. M., MSU, pp. 64-65; 1976; (Russian).
- LITVIN, L. F. and MIRGORODSKAIA, N. N.; Cartografical-statistical method of estimation of slope inclination; In coll. Regularity exposure erosion and riverbed processes in different natural condition. M., MSU, pp. 54-55; 1976; (Russian).
- MIRTSKHOULAVA, T. E.; Methodical recommendation for prognosis of the water (rain) erosion of soil; Methodical recommendation worked out by academician of Vaskhnil Ts. E. Mirtskhoulava, Moscow, 60 pp.; 1978; (Russian).
- GOGICHAISH VILI, G. P. and GORJOMELADZE, O. L.; Estimation of Soils Protection of Agricultural Plants in Georgia; *Bull. Of the Georgian Academy of Sciences*; 158(2):303–305; 1998.
- WISCHMEIER, W. H., JOHNSON, C. B. and CROSS, B. V.; A soil erodibility nomograph for farmland and construction sites; *J. of Soil and Water Conservation*; 26(5):189–193; 1971.
- WISCHMEIER, W. H. and SMITH, D. D.; *Predicting rainfall erosion losses, a guide to conservation planning*; no. 537 in Agricultural Handbook; USDA, Washington DC;

1978.

ZASLAVSKI, M. N.; *Soil Erosion*; Publishing House "Misl", Moscow; 1979; (Russian), 243 p.

ZASLAVSKI, M. N., LARIONOV, G. F., DOKUDOVSKAIA, O. G. and TARABRIN, N. P.; A map of erosion index of precipitation in the European territory of the USSR and Caucasus; In Coll. Soil Erosion and River Bed Processes. M., Publ. MSU, 1981, Issue 8, p. 17-29; 1981; (Russian).



## Buchbesprechungen

**William Gamboa; 2005**

**Producción agroecológica: una opción para el desarrollo del cultivo del Chayote**  
(*Sechium edule* /Jacq./ Sw.)

219 Seiten mit zahlreichen Abbildungen, Tabellen, Fotos und Zeichnungen, Editorial de la Universidad de Costa Rica, 2005, ISBN: 9977-67-911-8. Preis: 15,00 €.

Die Chayote, Güisquil oder Pear Squash hat in den vergangenen zwei Jahrzehnten auch die Märkte außerhalb des hispanischen Kontinentes erobert. Dazu trugen sowohl die gute Haltbarkeit und Transporteigenschaften als auch die vielfältigen kulinarischen Verwendungsmöglichkeiten von Früchten, Wurzeln und Blättern dieses ausdauernden tropischen Kürbisgewächses bei. Eine umfassende wissenschaftliche Abhandlung über *Sechium edule* fehlte bisher auf dem internationalen Büchermarkt. In jahrelangen akribischen Literaturrecherchen, Feldarbeiten und Forschungsstudien erarbeite GAMBOA ein übersichtlich gestaltetes, reich bebildertes und instruktives Nachschlagewerk. Die Monographie ist in vier Teile gegliedert. In den ersten drei Kapiteln werden Herkunft, Taxonomie, Botanik und die ökophysiologischen Ansprüche von Chayote ausgewogen und inhaltsreich dargestellt. Das Kapitel 4 ist dem Auftreten von Krankheiten, Schädlingen und Unkräutern gewidmet. In den folgenden beiden Kapiteln werden praktische Erfahrungen zum intensiven Chayoteanbau aus den weltweit wichtigsten Anbauregionen zusammengefasst. Der Exkurs führt von den möglichen Methoden der Bodenbearbeitung, über die Pflanzgutgewinnung, Pflanz- und Stützsysteme, die Düngung, den integrierten Pflanzenschutz, die Bewässerung bis hin zu den Erntemethoden, dem Nacherntemanagement, der Kommerzialisierung und dem betriebswirtschaftlichen Ergebnis. Der vierte Teil beinhaltet fünf Kapitel, die sich den Möglichkeiten und Hemmnissen des ökologischen Anbaues von Chayote stellen. Damit beschreitet der Autor absolutes Neuland für diese Kultur. Anhand von eigenen Untersuchungen und Studien werden züchterische und sortenspezifische Charakteristika dieser Spezie aufgeführt, nachhaltige Anbaupraktiken diskutiert, der organische Anbau von Chayote vorgestellt, faire Handelspraktiken diagnostiziert und soziokulturelle Besonderheiten der exportorientierten Chayoteanbauer beschrieben. Die zusätzlichen Daten und Beispiele im Anhang runden in gekonnter Weise dieses fakten- und informationsreiche Werk für Wissenschaft und Praxis ab.

J. Pohlen, Bonn

**Franz Alt, Rosi Gollmann und Rupert Neudeck; 2005**

**Eine bessere Welt ist möglich**

**Ein Marshallplan für Arbeit, Entwicklung und Freiheit**

Riemann Verlag, München, ISBN 3-570-50069-1, 320 Seiten, 19,- €.

Ein Marshallplan für Zwei Drittel der Menschheit, wäre das möglich?

Die drei Autoren, mit der Situation, gerade der Krisenregionen der Welt, gut vertraut fordern dies und sehen dafür auch Möglichkeiten. Das Buch mit den Kapiteln "Entwicklungspolitik ist Friedenspolitik" (Franz Alt), "Praktische Entwicklungszusammenarbeit mit menschlichem Gesicht" (Rosi Gollmann) und "Von Lügen, Lobbys und echter Hilfe" (Rupert Neudeck) beschreibt Situationen, die größtenteils bekannt sind und doch nicht so wahrgenommen werden. Schaffen wir nur noch größere Spenden bei Naturkatastrophen und wollen das tägliche Elend nicht mehr sehen? Dabei wird von allen dreien gut beschrieben, was erreicht werden kann, wenn wir es denn nur wollen. Arme und Reiche müssen sich entwickeln und die europäischen Länder sind dabei an ihr wohl verstandenes Eigeninteresse erinnert, siehe die Situation in den spanischen Enklaven in Afrika. Die Regierungschefs der EU-Staaten haben den Anstieg der Entwicklungshilfe festgeschrieben und ein Viertel der europäischen Hilfe könnte durch bessere Koordination sinnvoller ausgegeben werden (Die Zeit, 20.10.2005, S. 40). Die drei Autoren beeindrucken durch ihr Engagement, aber auch durch ihre Vorschläge und ihre Zuversicht in eine bessere Welt. Nicht Vorschriften, sondern Köpfe, die handeln sind gefordert. Dabei ist der Respekt vor der Würde des Menschen wichtig und die betroffenen Menschen müssen ihre Prioritäten selbst setzen. Das Buch berührt und ist nicht nur denjenigen, die sich schon mit Entwicklungshilfe befassen, sondern gerade auch Politikern zum Lesen wärmstens empfohlen.

H. Hemann, Witzenhausen

---

**Wyk, Ben-Erik van; 2005**

**Handbuch der Nahrungspflanzen. Ein illustrierter Leitfaden**

Stuttgart (Wissenschaftliche Verlagsgesellschaft) 2005, 479 S. mit 1009 Farbfotos. ISBN 3-8047-2246-6, Preis 39,- €

**Food Plants of the World - identification, culinary uses and nutritional value**

Pretoria (BRIZA Publications) 2005, 480 pp. ISBN 1-875093-56-7, price 39,- €

Der sehr produktive Autor hat schon wieder ein Werk abgeliefert - diesmal gleich in zwei Sprachen. Die englische Version ist das Original, deutsche Übersetzung: Friedel Herrmann. Das Ergebnis ist überzeugend. Es liegt ein Kompendium vor, das neben einer Einleitung (36 Seiten, geographische Herkunft, Charakterisierung der wichtigsten Nahrungspflanzengruppen) im Hauptteil (S. 36 - 391) die wichtigsten Nahrungspflanzen

beschreibt und ausführlich mit Farbfotos illustriert (*Abelmoschus esculentus* bis *Ziziphus jujuba*, insgesamt 354 Pflanzen!). Es ist damit eines der wenigen Werke, die die Vielfalt der Kulturpflanzen eindrucksvoll demonstrieren. Zu jeder Pflanze (meist Art, aber zuweilen auch infraspezifische Gruppe) gibt es eine Beschreibung, Bemerkungen zu Herkunft und Geschichte, zu den verwendeten Teilen, zur Kultur, zur Verwendung und zum Nährstoffgehalt. Gelegentlich folgen noch Anmerkungen.

Der Rezensent hat die Daten stichprobenartig geprüft und insgesamt für gut befunden. Die Abbildungen sind meist hervorragend. Bedauerlich sind einige Fehlbestimmungen. So ist 'Witloof' nicht *Cichorium endivia*, obwohl gelegentlich auch "Endivie de Witloof" genannt, sondern *C. intybus*. Unter *Lathyrus sativus* ist *L. latifolius* als "Gartensorte" abgebildet. Auch die Samen gehören nicht zur beschriebenen Art. Bei *Lupinus albus* handelt es sich um eine andere Art. *Ruta graveolens* (Abb. rechts unten) ist eine typische *Ruta chalepensis*. Die botanischen Namen (mit Autoren) sind überwiegend korrekt geschrieben. Kleinere Fehler wie *Gossypium arboretum* = *G. arboreum* oder *Kaempferia galangal* = *K. galanga* kommen vor.

Den Abschluß des Werkes bilden nahrungsmittelchemische Erläuterungen, eine alphabetische Kurzübersicht zu den Nahrungspflanzen (ca. 800 Sippen), ein Glossar und ein Register der wissenschaftlichen und Trivialnamen. Das Buch verdient eine weite Verbreitung.

K. Hammer, Witzenhausen

---

**Jansen, P.C.M. & Cardon, D. (Editors); 2005**

### **Plant Resources of Tropical Africa 3. Dyes and tannins**

PROTA Foundation, Wageningen, Netherlands / Backhuys Publishers, Leiden, Leiden, Netherlands / CTA Wageningen, Netherlands. 216 pp. ISBN 90-5782-159-1 (book only), price €25 (Industrialized countries), €12.50 (Developing countries). ISBN 90-5782-160-5 (book + CD-Rom), price €32 (Industrialized countries), €16 (Developing countries).

### **Ressources végétales de l'Afrique tropicale 3. Colorants et tanins (Transduction)**

Fondation PROTA Wageningen, Pays-Bas/CTA, Wageningen, Pays-Bas. 238 pp. ISBN 90-5782-163-X (livre seul), price €25 (Pays industrialisés), €12.50 (Pays en développement). ISBN 90-5782-164-8 (livre et CD-Rom), price €32 (Pays industrialisés), €16 (Pays en développement).

Treatments covering the diversity of African useful plants are still very rare. Therefore, this volume is an excellent source of information. This can be demonstrated e.g. by comparing the species included with those of the world treatment of P. Hanelt (ed.), 2001., Mansfeld's Encyclopedia of Agricultural and horticultural Crops. The following candida-

tes could be found for possible new inclusion into that compilation or confirmation of species only occasionally mentioned:

- *Arnebia hispidissima* (Sieber ex Lehm.) DC. (Boraginaceae)
- *Bruguiera gymnorhiza* (L.) Savigny (Rhizophoraceae)
- *Craterispermum laurinum* (DC.) Benth. (Rubiaceae)
- *Craterispermum schweinfurthii* Hiern (Rubiaceae)
- *Euclea divinorum* (Ebenaceae)
- *Ficus glumosa* Delile (Moraceae)
- *Flemingia grahamiana* Wight et Arn. (Papilionaceae)
- *Impatiens tinctoria* A. Rich. (Balsaminaceae)
- *Indigofera longiracemosa* Boivin ex Baill. (Papilionaceae)
- *Lannea barteri* (Oliv.) Engl. (Anacardiaceae)
- *Pauridiantha rubens* (Benth.) Bremek. (Rubiaceae)
- *Psilanthus ebracteolatus* Hiern (Rubiaceae) - can be successfully hybridized with *Coffea arabica*!
- *Pterocarpus angolensis* DC. (Papilionaceae)
- *Pterolobium stellatum* (Forssk.) Brenan (Caesalpinaceae)
- *Rathmannia longiflora* Salisb. (Rubiaceae)
- *Xylocarpus granatum* J. Koenig (Meliaceae)

After finishing the edition of the well Known PROSEA, PROTA (Plant Resources of Tropical 'Africa) Makes great progress. From the 16 volumes (apart from the precursor) now already the second appeared. Species which harvest dyes and tannins are treated in alphabetical order according to accepted Latin names. For each entry the following data are provided: Protologue, Family, Chromosome number, Synonyms, Vernacular names, Origin and geographical distribution, Uses, Production and international trade, Properties, Adulterations and substitutes, Description, Other botanical information, Anatomy, Growth and development, Ecology, Propagation and planting, Management, Diseases and pests, Harvesting, Yield, Handling after harvest, Genetic resources, Breeding, Prospects, Major references, Other references, Source of illustrations and authors. For the important species figures and distribution maps are shown.

The volume is completed by a list of plants providing dyes and tannins but with other primary use (8 pages), literature (pp. 177 - 205, astonishingly the above mentioned "Mansfeld" is not included), and indices of scientific and vernacular plant names. A very useful and comprehensive volume of Afrika's plant dyes and tannins.

K. Hammer, Witzenhausen

---

## Kurznachrichten

### **A new Master Programme MSc International Food Business and Consumer Studies**

#### **Objectives**

The politics of food in society, involving manufacturers, retailers, consumers and health professionals, are complex and continually evolving. This program enables its students to take on responsible tasks in national and international enterprises in the food business, as well as in food certification organisations. In particular, they are qualified

- to manage complex processes in enterprises in food industries and food trade as well as farms
- to develop and market food products and related services according to the needs of different consumer groups.

The graduates, with their flexibility of thinking and wide range of knowledge and skills, are proving increasingly attractive to employers. Graduates are qualified for further postgraduate studies, esp. PhD programs.

#### **Course Structure**

The postgraduate programme is characterised by a multidisciplinary approach at the interface between agriculture, food business and consumer science, within an international context. The MSc 'International Food Business and Consumer Studies' is a joint venture of two German Universities: The University of Kassel in Witzenhausen (Organic Agricultural Sciences) and the University of Applied Sciences Fulda (Nutritional, Food and Consumer Sciences).

One semester abroad is recommended. Project partners, particularly in Middle and Eastern Europe, are available to the students. The regular duration of study is four semesters (2 years; 120 ECTS Credits).

#### **Admission Requirements**

The programme aims at graduates, which hold a Bachelor's, or equivalent degree in the field of consumer science, nutrition, food science, food technology or agricultural science. Candidates with a background in economics and related fields possess appropriate knowledge and skills at degree standard in fields related to food and agricultural economics/business.

Applicants whose first language is not English should be able to demonstrate a satisfactory level of spoken and written English (TOEFL 61 - Internet based)

#### **Application deadline**

EU Nationals: August 1

Non EU Nationals: Students need to apply by March 1 to allow time for registration, financing and visa-formalities.

*For further information please contact:*

Faculty of Organic Agricultural Sciences  
Steinstr. 19  
D-37213 Witzenhausen  
Germany

Phone: +49.5542.98 1216  
Fax: +49.5542.98 1313  
Email: ifbc@uni-kassel.de  
Internet: [www.agrar.uni-kassel.de/ifbc](http://www.agrar.uni-kassel.de/ifbc)

## Announcement Tropentag 2006



Prosperity and Poverty in a Globalized World -  
Challenges for Agricultural Research  
October 11 - 13, 2005, University of Bonn, Bonn, Germany

### General information

The annual Conference on Tropical and Subtropical Agricultural and Natural Resource Management (DEUTSCHER TROPENTAG, DTT) is jointly organized by the universities of Berlin, Göttingen, Hohenheim, Bonn and Kassel-Witzenhausen as well as by the Council for Tropical and Subtropical Research (ATSAP e.V) in cooperation with BEAF/ GTZ.

DTT Tropentag 2006 will be held in Bonn. All students, Ph. D. students, scientists, extensionists, decision makers, politicians and practical farmers, interested and engaged in Agricultural Research and Rural Development in the Tropics and Subtropics are invited to participate and to contribute.

### Target of the Conference

Meeting, exchange of knowledge and experience and interdisciplinary, scientific discussions on global challenges - to balance the production of sufficient, high quality food for an ever increasing world population and

- ▷ an improved livelihood, health and education of the rural population as well as reduced pressure on the environment caused by agricultural production.
- ▷ Information exchange on new approaches to optimize the utilization of scarce resources like soil, energy and water.

### Plenary Session

Tomorrow's world should not be worse than today's! Sustainability can only be achieved by situation-conform traditional and/or new technologies in agriculture and thorough and efficient utilization of scarce resources but crucial is also the political, economic environment.

Invited international speakers will present their views, policy, philosophy and recommendation.

### Special Session

On the occasion of this conference a special plenary session will be devoted to the presentation of the

- ◇ "Hans H. Ruthenberg-Graduate-Award" and the
- ◇ "Josef G. Knoll-Science-Award"

by the "Vater and Sohn Eiselen Stiftung", Ulm

### Programme Coordination

- ◇ Prof. Dr. Klaus Becker
- ◇ Dr. Christian Hülsebusch
- ◇ Dr. Eric Tielkes

on behalf of the Board of the Centre for Agriculture in the Tropics and Subtropics.

### Further Information:

Dr. Folkard Asch  
University of Bonn  
Plant Nutrition in the Tropics and Subtropics  
Karlrobert-Kreiten-Straße 13  
D-53115 Bonn, GERMANY

Phone: +49 (0)228 - 73-1678  
Fax: +49 (0)228 - 73-2489  
Email: fa@uni-bonn.de  
Internet: www.tropentag.de

## **Notes to authors**

The Journal of Agriculture in the Tropics and Subtropics publishes papers and short communications dealing with original research in the fields of rural economy and farm management, plant production, soil science, animal nutrition and animal husbandry, veterinary hygiene and protection against epidemics, forestry and forest economy.

The sole responsibility for the contents rests with the author. The papers must not have been submitted elsewhere for publication. If accepted, they may not be published elsewhere without the permission of the editors.

Manuscripts are accepted in German, English, French, and Spanish. Papers may not be published in the order of receipt, those that require minor amendments, only are likely to appear earlier. Authors are advised to retain one copy of the manuscript themselves as the editors cannot accept any responsibility for damage or loss of manuscripts.

### *1. Contents of the manuscripts*

Findings should be presented as brief as possible. Publication of a paper in consecutive parts will be considered in exceptional cases.

The following set-up is recommended:

The introduction should be as brief as possible and should concentrate on the main topics of the paper. Reference should be made to recent and important literature on the subject, only.

Materials used and methods applied should be explained briefly. Well-known or established methods and procedures should not be described. New or important methods should be explained. With all its brevity, this part should enable the reader to assess the findings adequately.

Tables and Figures should be used to effectively present the results. Explanations and other remarks on the results can be included in the text.

Discussion of results should also refer to relevant literature on the topic and lead to clear conclusions. Recommendations with respect to further research needed on the respective subject will increase the value of the paper.

The summary should concentrate on the main results and conclusions to highlight the author's contribution. It should be suitable for information storage and retrieval.

### *2. Form of the manuscripts*

Manuscripts should be typed double-spaced with a wide margin, preferable on disk.

The documents should be prepared with standard software (Microsoft Word, Word Perfect,  $\text{\LaTeX}$ ). Alternatively, the manuscript can be submitted as a simple text/rtf file together with a printed version of the original format.

Please do not use automated or manual hyphenation.

Title, headings and references (names of authors) should not be in capitals.

Tables and figures should be attached at the end of the document or separately. The preferred position for the insertion of tables and figures should be marked on the margin of the text.

The manuscript should not be longer than 15 typed pages including tables, figures and references.

The title of the paper is followed by the name(s) and address(es) of the author(s).

The abstract should be followed by a list of keywords (up to eight).

For each paper, a summary must be submitted in the same language (not more than 20 lines) and in English, if the paper is written in an other language.

Tables should not be prepared with blanks and should fit on a DIN A5 page (max. width: 12cm (landscape: 18.5cm) with a minimum font-size of 7pt. ).

All tables should have captions and should be numbered consecutively.

Figures should be black&white/greyscaled and suitable for reproduction (if possible, vector formats, postscript .ps .eps). Photos should be high-gloss prints of good contrast, maximum size 13 by 18 cm, line drawings with Chinese ink on white or transparent paper. All figures should be numbered consecutively. A separate list of captions for illustrations has to be added.

S.I. (System International) units have to be used throughout.

References in the text should be made by the name of the author and the year.

Each paper should have an alphabetical list of references giving name and abbreviated first name of the author(s), title of the paper, name of the journal, number of the volume, year, page numbers; for books: title, place of publication, and year.

On publication, each author will receive two copy of the Journal

Manuscripts and communication should be addressed to:

Journal of Agriculture and Rural Development in the Tropics and Subtropics, former  
Der Tropenlandwirt/Beiträge zur tropischen Landwirtschaft und Veterinärmedizin  
Editorial Board

Steinstrasse 19,D-37213 Witzenhausen

E-mail: tropen@wiz.uni-kassel.de , Fax (0) 5542 981313

April 2004