NONWOVENS USED IN HORTICULTURE – OPTIMIZATION OF NEEDLE PUNCHING PROCESS PARAMETERS

NEȚESUTE FOLOSITE ÎN HORTICULTURĂ – OPTIMIZAREA PARAMETRILOR PROCESULUI DE INTERȚESERE

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Abstract. *Textile fabrics have a long history of use in agriculture. The term "agrotextile" now is used to categorize the woven, nonwoven and knitted fabrics used for agricultural and horticultural applications. Among the major sectors and specific applications that are considered to have potentials for jute/synthetic nonwovens in agriculture/horticulture are frost protectors. The purpose of this paper is to investigate the influence of needling punching process parameters on functional properties of nonwovens used as frost protectors. The study was focused on the influence of needling density and needle gauge on jute/polypropylene nonwoven density and water vapour permeability by using a central, composite design for second-order. The results show that the process parameters have a significant influence on nonwoven characteristics. The higher of process parameters values, the higher is fabric density. A less porous nonwoven have a lower water vapour permeability which means that the agrotextile conserves water by reducing evaporation.*
Key words: *agrotextile**,** nonwoven**,** composite design*

Rezumat. *Textilele au o lungă istorie a utilizării lor în agricultură. Termenul de „agrotextil" este folosit pentru a defini textilele țesute, nețesute sau tricotate utilizate în aplicații agricole şi horticole. Printre principalele sectoare şi aplicații specifice ale agriculturii/horticulturii în care se pot utiliza nețesute din iută/fibre sintetice se numără materialele de protecție la îngheț. Scopul acestei lucrări este de a investiga influența parametrilor procesului de interțesere asupra proprietăților funcționale ale nețesutelor utilizate pentru protecție. Studiul s-a axat pe influența densității de interțesere şi a fineții acelor asupra densității şi a permeabilității la vapori de apă utilizând un model matematic central compus rotabil de ordinul doi. Rezultatele studiului au indicat faptul că parametrii procesului de interțesere au o influență semnificativă aspura caracteristicilor studiate. Odată cu creşterea valorilor optimizate creşte densitatea nețesutului. Un nețesut mai puțin poros are o permeabilitate la vapori mai mică cee ce înseamnă că agrotextilul conservă apa prin reducerea evaporării acesteia.*
Cuvinte cheie: *agrotextil, nețesut, model compus*

INTRODUCTION

Agrotextiles are nowadays extensively being used in horticulture, farming and other agricultural activities. Agrotextiles play a significant role to help control

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environment for crop protection, reduce variations due to climate or weather change and therefore they can generate optimum condition for plant growth.

Spun bonding and needle punching techniques are widely used for the production of nonwoven agrotextiles. Needle punching is a process for converting webs of fibers into coherent fabric structures, generally by means of barbed needles, which produce mechanical bonds within the web (Purdy, 1980).

Among the major applications that are considered to have potentials for jute/synthetic nonwovens in agriculture are frost protectors. Nonwovens are generally used in order to enhance crop growth and production by increasing both air and soil temperatures, reducing the water evaporation and wind damage. A medium weight nonwoven will give from 2 to 6 degrees of frost protection (Olle *et.al.,* 2010).

In order to understand more about the influence of needling process parameters on nonwoven characteristics it is essential to use mathematical modeling which is an investigation method of technological processes based on experimental data collection and processing. The present study is investigating the effect of two parameters on the functional characteristics of nonwoven that can contribute to reducing the water evaporation and of course the costs with water, labour etc. For this purpose, a central composite design for second-order model has been employed.

MATERIAL AND METHOD

A blend of jute (75%) and polypropylene (25%) fibers was used to prepare nonwoven samples. These raw materials were chosen due their environment-friendliness, widespread presence in the market and cheap price. The jute fibers used had an average length of 80 mm and fineness 27 dtex and the polypropylene fibers of 50 mm and 7.7 dtex.

Nonwoven samples were prepared on a pilot plant single needle-punching machine Automatex, equipped with universal card type CA 500, cross-lapper model MFA 600 and needle-punching loom type MPR 600. The basis weight of the webs of jute/polypropylene fibers formed by carding and lapping process was controlled as 220 g/m^2. The webs were fed to the needling zone on a needle loom type Automatex having Groz-Beckert needles with two barbs on each edge and various finenesses (gauge) (for e.g. 15x18x3xC222 G3017). The needle-punched fabrics were produced by the penetrating action of barbed needles which reorientation and intermingles the fibers from a horizontal to a vertical direction (Rusell, 2007).

The experiments took place under pilot unit conditioned. Before performing the measurements, the samples were conditioned at 65%, relative humidity and 20^{0}C temperature for 24 h.

Mass (W) was tested according to the standard ISO 9073-1:1989 Textiles – Test methods for nonwovens – Part 1, whereas thickness (T) was tested according to the standard for nonwoven textile ISO 9073-2:1995. Density of nonwoven textiles was calculated from mass per unit area and thickness values, using the following equation:

$$\rho_N = \frac{W}{T}\left[kg/m^3\right] \quad (1)$$

The water vapour permeability of the nonwoven samples was measured according to the standard ASTM E96. Six circular specimens, 6 cm in diameter, were cut from each fabric. A 145 ml aluminium cup was filled with distilled water, covered with the fabric specimen. The whole assembly was then weighed and reweighed after a certain elapse of time (3, 24, 48 and 72 hours). The water vapour permeability (WVP) was calculated using the following formula:

$$WVP = \frac{G/t}{A} \quad (2)$$

where *G* = weight change (g), *t* = time during which *G* occurred (h) and *A* = test area (m^2).

In order to study the influence of the needling-punching process parameters on fabric density and water vapour permeability a central composite surface factorial design of two variables was used (Lupu *et. al.,* 2013, Taloi, 1987). The useful limits of the two variables used in the central composite design, i.e. needling density and needle gauge, were selected by conducting a number of preliminary experiments. The limits, actual and coded values of factors are given in Table 1.

Table 1

Actual and coded values of independent variables

Variable	**Symbol**	**Code**				
		-1.414	-1	0	1	+1.414
Needling density (punches/cm^2)	x_1	60	73	105	137	150
Needle fineness (gauge)	x_2	30	32	36	40	42

RESULTS AND DISCUSSIONS

The obtained matrix was a 13-points central composite design, which consisted of a full factorial design 2^2 (4) plus five center points and four star points. Thus, the 13 experimental samples allowed the estimation of the linear, quadratic and two-way interactive effects of various factors on nonwoven properties.

The developed matrix design, including the coded values of the factors and actual values of different samples and their properties are shown in Table 2.

To correlate the effect of independent variables and response, the following second-order standard polynomial was considered (Cojocaru *et al.,* 1968):

$$Y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2 \quad (3)$$

where *Y* represents the response and $b_0, b_1, \ldots, b_{12}$ are the coefficients of the model.

The coefficients of main and interactive effects were determined using the standard method (Cojocaru et al., 1968). The regression coefficients of the proposed model for different parameters can be calculated. To establish the relationship between the independent variables (x_1) and (x_2) and the dependent variable (*Y*), a regression analysis was performed as describe above. The regression coefficients were used in the quadratic-proposed polynomial model (Table 3) to determine the predicted response values. These coefficients have either positive or negative value, and accordingly have an effect on the experimental results. The coefficients of R^2 multiple correlation and the *F*-values together with the response surface equations of the factorial design for second-order models after testing the regression coefficients by employing the student test are shown in Table 4.

To check the significance of multiple correlation coefficients, we used the *F* test (Taloi, 1987). Accordingly, *F*-ratios were calculated for a 95% level of confidence and two degrees of freedom (f_1 =2 respectively, f_2=10) and then compared with the corresponding tabulated values. If the calculated values of *F*-ratios exceed the corresponding tabulated values, then the independent variables had a significant influence on the dependent variable. The tabulated value of the *F*-ratio at 95% level of confidence was found to be 4.1 (Cojocaru *et al.,* 1968).

Table 2

Constructional details of experimental fabrics

Sample No	Needling density (x_1)	Needle gauge (x_2)	Fabric density (kg/m^3)	Water vapour permeability ($g/m^2.h$)
1	-1	-1	65.259	15,706
2	1	-1	60.741	17,331
3	-1	1	63.769	17,266
4	1	1	67.082	14,753
5	-1.414	0	63.043	16,855
6	1.414	0	69.494	17,115
7	0	-1.414	61,689	16,053
8	0	1.414	66,053	17,050
9	0	0	65,955	10,130
10	0	0	64,489	11,070
11	0	0	65,048	11,105
12	0	0	67,026	9,814
13	0	0	64,519	10,312

Table 3

Quadratic proposed polynomial models

Quadratic proposed polynomial models	
(1) Fabric density Y_1=	$65.423+0.99x_1+1.378x_2+0.203x_1^2-0.995x_2^2+1.958x_1x_2$
(2) Water vapour permeability Y_2=	$10.49-0.065x_1=0.0409x_2=3.12x_1^2+2.903x_2^2-1.035x_1x_2$

The values of the multiple correlation coefficients (Table 4) between the experimental data and the predicted values illustrate a very good and significant correlation.

The fabric density equation Y_1 (Table 4) reveals that the needling density (x_1) and needle gauge (x_2) have a significant influence on the characteristic described by the equation. Moreover, the coefficients of the first degree term have the same sign (b_1>0, b_2>0) indicating the effect of independent variables to be the same. The presence of second degree-term coefficient (x_2^2) indicates a well-defined response surface. The effect of independent variables on fabric density is shown in Figure 1. In addition, a considerable influence has the interaction term x_1x_2 whose positive coefficient shows an increasing tendency of the fabric density on the cumulative action of both parameters. As can be seen from Figure 1, the mathematical model Y_1 describes a hyperboloid with saddle point having the following coded values: x_1= -1.218 and x_2= -0.505. The actual values of the critical point obtained by optimization are x_1=66 punches/cm^2 and x_2=32 gauge for a fabric density Y_1=60.884 kg/m^3.

The higher the needling density for the same needle gauge, the higher is the fabric density due to the strong fiber peg formation as more number of fibers are arranged vertically (Sengupta and Sengupta, 2013). A higher fabric density means a higher compactness of the nonwoven. Regarding the increase of needle gauge, the action is softer than the action of needling density (as evidenced previously also Sengupta, 2005). The number of fibers at the surface pulled deep into the fabrics structure is smaller for the 40 gauge needle than for the 32 gauge needle (Lupu *et al.*, 2013) leading to increased fabric weight which means a higher fabric density, for the same needling density. Therefore, the critical point cannot be considered an optimum point for the nonwoven used as frost protector.

Table 4

Response surface equation after testing of regression coefficients and evaluation of multiple correlation coefficient

Response	Response surface equation	Coefficient of multiple correlation	F -ratios
Y_1=	$65.423+0.99x_1+1.378x_2-0.995x_2^2+1.958x_1x_2$	0.8316	11.21
Y_2=	$10.49+3.12x_1^2+2.903x_2^2-1.035x_1x_2$	0.988	204.59

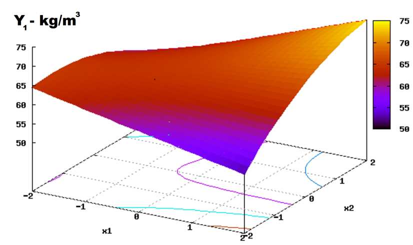

Fig. 1 - Effect of needling density (x_1) and needle fineness (x_2) on fabric density Y_1 (kg/m3)

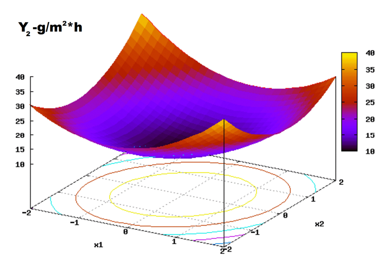

Fig. 2 - Effect of needling density (x_1) and needle fineness (x_2) on water vapour permeability Y_2 (g/m^2.h)

Inspection of the equation of Y_2 (Table 4) indicates an influence of needling density and needle gauge on water vapour permeability through a second–degree term. Also, the coefficients of the second-degree terms indicate a well-shaped response surface. A considerable influence has the interaction term. The negative sign of the interaction term coefficient indicates a decreasing tendency of the water vapour permeability to the cumulative action of both parameters. The effect of independent variables on water vapour permeability is presented graphically in Figure2. The mathematical model of Y_2 describes an elliptical parabolic dependency with a minimum point having x_1= 0.00 and x_2 = 0.00 as coded values. The actual values of the critical point are x_1= 105 punches/cm^2 and x_2= 36 gauge for a water vapour permeability Y_2=10.490 g/m^2.h.

The increase in needle gauge over a certain value (36 gauge) is responsible for a smaller entanglement of the fibers resulting in a more bulky fabric structure. Thus, the water vapour permeability is increasing due to the higher number of voids through which the water can be evaporated faster. Agrotextiles must conserve water by reducing evaporation. Hence, a minimum value for the water vapour permeability means a reduction of evaporation so the critical point can be considered an optimum. Another study has focused on the analysis of the same processing parameters (Lupu *et. al.,* 2013) in order to establish the relationship between needling-punching process parameters (needling density and needle gauge) and thermal conductivity of the same obtained nonwovens. The water vapour permeability and thermal conductivity (main properties) can be changed by changing the two studied process parameters to ensure frost protection function of nonwovens.

CONCLUSIONS

A series of cross-laid needlepunched nonwoven agrotextiles was produced based upon a central composite design for second-order model by varying the process parameters. We investigated the effect of two parameters on the physical properties of needlepunched nonwoven agrotextiles used as frost protectors. We found that the needling density and needle gauge have a significant effect on fabric density whereas the needle gauge has a major influence on water vapour permeability. The information available from contour diagrams regarding the interaction of parameters on fabric density and water vapour permeability is very useful for designing a needle-punched nonwoven fabric for agricultural applications.

Water vapour permeability is highly correlated with fabric density. A higher fabric density means a higher compactness of the nonwoven structure which can conserve water by reducing evaporation.

Using nonwovens in agricultural applications it is recommended based on several advantages like less expensive, easy to install and protects crops against low temperature and frost.

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