INFLUENCE OF NEEDLING PROCES PARAMETERS ON NONWOVENS USED AS IRRIGATION SUBSTRATES

INFLUENȚA PARAMETRILOR PROCESULUI DE INTERȚESERE ASUPRA NEȚESUTELOR FOLOSITE CA SUBSTRATURI DE UDARE

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Abstract. *Nonwovens used as watering substrate distibute water uniformlyand act as slight water buffer owing to the absorbent capacity. So, the irrigation solution is brought directly to the root zone. At the same time, using of nonwovens with higher water holding capacity affects the frequency of irrigation which depends by existing environmental conditions. In this study, we present the influence of the needling process parameters on the functional characteristics of nonwovens used as irrigation substrate. The aim is to determine optimal processing parameters using a central, composite design for second-order model. Our results show that the needling process parameters have a significant influence on functional characteristics. The higher of needle depth penetration and needle board frequency, higher is the compactness of nonwoven (higher fabric density) due to the strong fiber peg formation as more number of fibers are arranged vertically. Also, a less porous nonwoven strauture has a lower water holding capacity.*
Key words: *irrigation substrate, nonwoven**,** central composite design*

Rezumat. *Nețesutele utilizate ca substraturi de udare distribuie apa uniform şi acționează uşor ca un tampon datorită capacității de reținere a apei. Astfel, soluția de irigare este adusă direct în zona rădăcinii. În acelaşi timp, folosire de nețesute cu capacitate mare de reținere a apei influențează frecvența de udare ce depinde de condițiile de mediu existente. În acest studiu se prezintă infşuența parametrilor procesului de interțesereasupra caracteristicilor funcționale ale nețesutelor utilizate ca substraturi de udare**.** Scopul lucrării este dea determina parametrii optimi de proces folosind un model matematic compus, central rotabil de ordinul doi. Rezultatele indică faptul că parametrii de interțesere au o influență semnificativă asupra caractericilor funcțional. Odată cu creşterea adâncimii de pătrundere a acelor şi a frecvenței păcii cu ace creşte compactitatea nețesutului datorită punctelor de consolidare mai solide ca urmare numărului mai mare de fibre aranjate vertical o structură mai puțin poroasă are o capacitate de reținere a apei mai mică..*
Cuvinte cheie: *substrat de udare, nețesut, model central compus*

INTRODUCTION

The possibility to create and manufacture nonwovens at lower cost can contribute to increase environmental protection. Nonwovens are used effectively for optimizing the productivity of crops, gardens and greenhouses. Their

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protective nature means that the need for pesticides is reduced and manual labour is kept to a minimum.

Water absorptive capacity is a very important property and an important criterion for the performance of needle-punched nonwovens used as irrigation substrate in horticulture (Sengupta, 2009).

Nonwovens used as watering substrate distribute water uniformly and act as slight water buffer owing to the absorptive capacity. So, the irrigation solution is brought directly to the root zone. At the same time, the using of nonwovens with higher water holding capacity affects the frequency of irrigation which depends by existing environmental conditions. Nonwovens can have a higher water absorbency if contain in the composition cellulose-based fibers. The advantages of using in the fibrous blend of PP fibers include lighter weight, high wet strength, resistance to rot and chemicals and quick wicking action.

Needle punching is a process for converting webs of fiber into coherent fabric structures, normally by means of barbed needles, which produce mechanical bonds within the web (Purdy, 1980). In order to understand more about the influence of needling process parameters on nonwoven water absorptive capacity it is essential to use mathematical modelling 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 functional characteristics of nonwoven that can contribute to reducing the irrigation frequency 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

All fabric nonwovens have been prepared from blends of 50% viscose of 3.3dtex/38 mm and 50% polypropylene of 6.7dtex/50 mm. A high percentage of viscose (cellulose-based fibers) has been used due to high capacity to hold water.

Web of polypropylene/viscose fibers was formed by carding and lapping process, respectively. The basis weight of the web was controlled as 150 g/m^2. The web was fed to the needling zone on a needle loom type Automatex having 15x18x42x3CBA Foster needles.

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 condition. Before performing the measurements, the samples were conditioned at 65%, relative humidity and 20^{0}C temperature for 24 h.

The samples were tested to determine their weight (W) and thickness (T) according to EDANA standards (ERT 40.-90, 1999, ERT 30.5-99, 1999, respectively). Then, the density of the nonwoven was calculated using the following relation:

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

The fabric water absorptive capacity was tested according to ISO 9073-6. The water absorptive capacity in (%) was calculated using the following relation:

$$C_a = \frac{M_d - M_w}{M_w} x100(\%) \qquad (2)$$

where: M_d: mass in g of the dry test sample:

M_w: mass in g of the wet test sample at the end of test.

RESULTS AND DISCUSSIONS

To study the individual and interactive influence of needle board frequency, expressed in cycles/min and needle depth penetration, expressed in mm, a central composite surface factorial design of two variables (Taloi, 1987), was used.

Estimation of the response from this factorial design model equation is suitable only when the independent variables are within the range for which the model has been developed. The useful limits of the two variables were selected by conducting a number of preliminary experiments. The limits and the actual and coded values of independent variables are given in Table 1.

Table 1

Actual and coded values of independent variables

Variable	Symbol	Code -1.414	-1	0	1	+1.414
Needle board frequency (cycles/min)	x_1	94	115	165	215	236
Needle depth penetration (mm)	x_2	3	4	6	8	9

The design developed matrix had 13 sets of experimental combinations in which 8 sets were distinguished and 5 sets referred to the central point. These 5 sets of experimental combinations from the central point were performed in order to establish the value of experimental errors.

The design matrix so developed with the coded values of independent variables and measured values of fabric density (kg/m3) and water absorptive capacity (%) 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):

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

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.

Table 2

Constructional details of experimental fabrics

Sample No	Needle board frequency, cycle/min (x1)	Needle depth penetration, mm (x2)	Fabric density (kg/m^3)	Water absorptive capacity (%)
1	-1	-1	44.296	1894
2	1	-1	49.580	2148
3	-1	1	47.954	1979
4	1	1	50.147	2017
5	-1.414	0	46.892	1850
6	1.414	0	51.673	1974
7	0	-1.414	47.944	2190
8	0	1.414	53.665	2102
9	0	0	46.936	2119
10	0	0	44.296	1994
11	0	0	44.500	2053
12	0	0	45.992	2081
13	0	0	45.223	2059

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Table 3

Quadratic proposed polynomial models

Quadratic proposed polynomial models	
(1) Fabric density Y_1=	$45.401+1.78x_1+1.539x_2+1.425x_1^2+2.185x_2^2-0.733x_1x_2$
(2) Water absorptive capacity Y_2=	$2061.69+58.417x_1-21.304x_2-79.856x_1^2+37.109x_2^2-54x_1x_2$

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

The values of multiple correlation coefficient (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 needle board frequency (x_1) and needle depth penetration (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.

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
$Y_1=$	$45.401+1.78x_1+1.539x_2+1.425x_1^2+2.185x_2^2$	0.9126	24.91
$Y_2=$	$2061.69+58.417x_1-79.856x_1^2+37.109x_2^2-54x_1x_2$	0.9312	32.63

The presence of second degree-term coefficients indicates a well-defined response surface. The effect of independent variables on fabric density is shown in Figure 1. As can be seen from Figure 1, the mathematical model Y_1 describes an elliptical parabolic dependency with a minimum point having the following coded values: x_1= -0.625 and x_2= -0.352. The actual values of the critical point obtained by optimization are x_1=134 cycles/min and x_2=5 mm for a fabric density Y_1=44.575 kg/m^3.

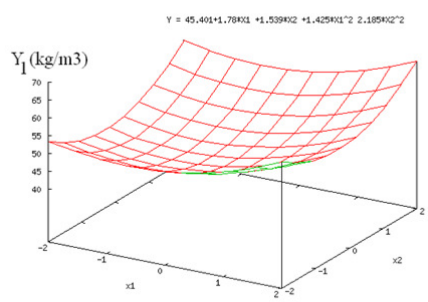

Fig. 1. Effect of needle board frequency (x_1) and needle depth penetration (x_2) on fabric density Y_1 (kg/m3)

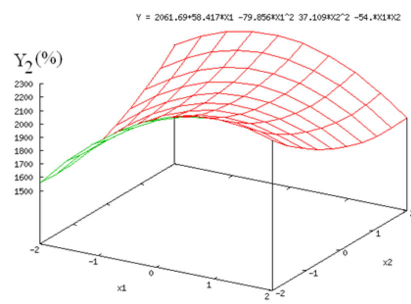

Fig. 2. Effect of needle board frequency (x_1) and needle depth penetration (x_2) on water absorptive capacity Y_2 (%)

The higher of needle board frequency and needle depth penetration, 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 and hence the number of pores (amount of voids) is decreasing. Therefore, the critical point which is a minimum point can be considered an optimum point for the nonwoven used as irrigation substrate.

Inspection of the equation of Y_2 (Table 4) indicates a significant influence of needle board frequency on water absorptive capacity through first–degree term. The coefficients of the second-degree terms also influence the water absorptive capacity and indicates 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 absorptive capacity to the cumulative action of both parameters. The effect of independent variables on water absorptive capacity is presented graphically in Figure 2. The mathematical model of Y_2 describes a hyperboloid with saddle point having x_1= 0.294 and x_2 = 0.214 as coded values. The actual values of the critical point are x_1= 180 cycles/min and x_2= 6.6 mm for a water absorptive capacity Y=2057.80%.

The increase in needle board frequency over a certain value and needle depth penetration are responsible for a better entanglement of fibers resulting in a more compact fabrics structure, with less number of voids. Thus, the water absorptive capacity is decreasing due to the lower amount of air present in a more compact fabrics structure which can be replaced by the water.

CONCLUSIONS

Second-order polynomials with two independent variables have been proposed with a good correlation for fabric density and water absorptive capacity of needle-punched, cross-laid nonwoven, with respect to mass/unit area of the web. From this model, one can understand the effects of different parameters on fabric density and water absorptive capacity and can also predict the water absorbency approximately knowing the values of parameters.

The information available from contour diagrams regarding the interaction of parameters on water absorbency and fabric density is very much useful to design a needle-punched nonwoven fabric for agricultural applications. It is known that water absorbency of nonwoven increases with the increasing of cellulose-based fibers proportion. Also, the needling process parameters can increase water absorbency until certain values. As needle depth penetration decrease for a particular needle board frequency, fabric density decrease due to weak fiber peg formation. An optimum fabric density of 44 kg/m^3 for a nonwoven used as irrigation substrate has been achieved at around 134 cycles/min and 5 mm needle depth penetration.

Water absorptive capacity is highly correlated with fabric density. So, as needle board frequency increase, for a particular needle depth penetration, the water absorptive capacity increases and after reaching to maximum, it decreases due to a less porous structure of nonwoven.

Using nonwovens in irrigation practices it is recommended based on following advantages: are less expensive and easy to install, allows for complete flexibility, keep foliage dry to minimize diseases and no runoff.

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