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# NITROGEN AND HYDROGEL COMBINATION IN OAT GRAINS PRODUCTIVITY

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**ABSTRACT**

Hydroretentors in the soil can facilitate the maintenance of moisture and contribute to the efficiency of nitrogen use to the development of oat grains. The objective of the study is to verify if there is an efficiency increase of nitrogen use in oat grains productivity by the use of hydrogel and, if the hypothesis is confirmed, to define the optimal combination of N-fertilizer with the biopolymer in high succession systems and reduced N-residual release. The study was conducted in 2014 and 2015, in a randomized block design with four replicates in a 4 x 4 factorial, for hydrogel doses (0, 30, 60 and 120 kg ha-1), added in the furrow with the seed and N-fertilizer doses (0, 30, 60 and 120 kg ha-1), applied at the stage of 4th leaf expanded, respectively. The use of different doses of the hydroabsorbent biopolymer associated to the nitrogen fertilization in the cover influenced positively the productivity of oat grains, regardless of year and succession system. The adjusted dose of hydrogel and nitrogen at the maximum grain productivity in the soy/oat system is around 65 and 80 kg $ha^{-1}$, respectively, and in the corn/oats system, 60 and 100 kg $ha^{-1}$ respectively, regardless of the cultivation year.



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## INTRODUCTION

Due to the high protein content and quality of the dietary fibers, the use of oat grains for food has received great acceptance by doctors, nutritionists, and consumers, requiring an increase in the productivity of this cereal in Brazil (Hawerroth *et al*., 2013; Mantai *et al*., 2016). The management technologies, genetics, soil conditions and favorable climate are essential to the increase in the oat grains productivity. Among the technologies, the management of nitrogen is essential to ensure high productivity and grain quality (Mantai *et al*., 2015; Todeschini *et al*., 2016). On the other hand, nitrogen shows great complexity of action on the environment, being easily leached in rainy years and volatilized in dry years, increasing production costs and generating environmental pollution (Filho *et al*., 2011; Silva *et al*., 2015).

One of the ways to improve the nitrogen absorption by plants is the maintenance of soil moisture, because the nitrogen supply to the plants depends, among other factors, on the humidity, aeration and temperature that interact with each other in the cropping systems (Rocha *et al*., 2008; Silva *et al*., 2015). The use of biopolymers can be an alternative to the maintenance of soil moisture, acting as a regulator of water availability and promoting efficiency in the use of nutrients (Dranski *et al*., 2013; Azevedo *et al*., 2016). The hydrogel biopolymer is a hydroabsorbent that retains large volumes of water into its structure, swells, forming a gel, and provides gradual release of volume stored to the plants (Azambuja *et al*., 2015). In addition, they act as soil conditioners, improving structural properties, permeability, and rates of infiltration, besides reducing water erosion and contributing to the efficient use of water (Bezerra *et al*., 2010; Silva *et al*., 2013).

Therefore, the use of biopolymers applied to the soil during the oat sowing may represent an innovative technology that favors the maintenance of moisture and improves the efficiency of nitrogen use in the elaboration of grains. The objective of the study is to verify if there is an increase in the efficiency of nitrogen use in the productivity of oat grains with the use of hydrogel, confirming the hypothesis to define the ideal combination of N-fertilizer with the biopolymer aimed to maximize the productivity of oat grains in high succession systems and reduced N-residual release.

## MATERIALS AND METHODS

The field experiments were conducted in 2014 and 2015 crop years, in Augusto Pestana, RS, Brazil (28° 26' 30"S latitude and 54° 00' 58" W longitude). The soil of the experimental area is classified as typical dystrophic red latosol and the climate is classified as Cfa, according to Köppen classification, with hot summer and without dry season. Ten days before sowing, soil analysis was performed and identified the following local chemical characteristics (Tedesco *et al.*, 1995): i) system corn/oat (pH= 6,5; P= 34,4 mg $dm^{-3}$; K= 262 mg $dm^{-3}$; MO= 2,9 %; Al= 0 $cmol_c$ $dm^{-3}$; Ca= 6,6 $cmol_c$ $dm^{-3}$ e Mg= 3,4 $cmol_c$ $dm^{-3}$) and; ii) soy system/oat (pH= 6,2; P= 33,9 mg $dm^{-3}$; K= 200 mg $dm^{-3}$; MO= 3,0 %; Al= 0 $cmol_c$ $dm^{-3}$; Ca = 6,5 $cmol_c$ $dm^{-3}$ e Mg = 2,5 $cmol_c$ $dm^{-3}$). Regardless of the crop year, sowing was carried out in the third week of June, according to the cultivation recommendation in the residual cover of high and low C/N, corn/oats and soy/oat systems, respectively. At sowing, the sowing-fertilizer was used in the composition of the plot with 5 lines of 5 m in length and spacing between rows of 0.20 m, forming the experimental unit of 5 $m^2$.

The population density was 400 viable $m^{-2}$ seeds, using the URS-Corona white oat cultivar. During the execution of the study, applications of tebuconazole fungicide were applied at a dosage of 0.75 L ha-1. The weed control was made with metsulfuron-methyl herbicide at a dose of 4 g $ha^1$, and additional weedings when necessary. In the experiments were applied at sowing 45 and 30 kg $ha^1$ of $P_2O_5$ and $K_2O$, based on the contents of P and K in the soil for seed productivity expectation of 3 t $ha^1$, respectively, and 10 kg $ha^{-1}$ of nitrogen at the base (except in the standard experimental unit), with the remainder to contemplate the proposed doses in the study, in the growth stage of fourth leaf expanded. It is noteworthy that the application of different doses of the hydrogel polymer was carried out next to the oat seed, at the same depth and culture line in the soil. The experiment was conducted in two cultivation systems, high and reduced release of N-waste (corn/oat and soy/oat systems) in a randomized block with four repetitions by following a factorial 4 x 4 in the sources of hydrogel at doses of 0, 30, 60 and 120 kg $ha^{-1}$, and N-fertilizer levels (urea supply) of 0, 30, 60 and 120 kg $ha^{-1}$. Grain productivity has been obtained by cutting three central lines of each plot at the maturity stage, with grain moisture around 22%. The plants were harvested with a stationary harvester directed to the lab for correction of grain moisture at 13% and weighed to estimate the grain productivity (GP kg $ha^{-1}$). Catering to the assumptions of normality and homogeneity via Bartlett tests (Stell *et al.*, 1997), variance analysis for detection of main and interaction effects was carried out. Through the Scott and Knott model, a comparison of grain productivity averages of hydrogel/nitrogen combinations was performed.

By the quadratic equations $(Y = b_0 \pm b_1 x \pm b_2 x^2)$, the optimal doses of N-fertilizer $(N_{ideal} = -\frac{b_1}{2b_2})$ and hydrogel $(H_{ideal} = -\frac{b_1}{2b_2})$ were estimated for the maximum productivity of grains under the conditions of use of nitrogen and biopolymer, in the cropping years and systems. In addition, for the adjustment of hydrogel and nitrogen combined doses, a response surface regression analysis was performed $(Z_i = \beta_0 + \beta_1 H_j + \beta_2 N_j + \beta_3 H_j^2 + \beta_4 N_j^2 + \cdots + \beta_n H_j N + \varepsilon_j)$, with $Z_i =$ dependent variable (grain productivity); $\beta_n =$ estimation of regression coefficients; H e N = values of treatment levels [nitrogen doses (0, 30, 60, 120 kg of N $ha^{-1}$) and doses of hydrogel (0, 30, 60, 120 kg of H $ha^{-1}$)]; $\beta_1 H_j$ e $\beta_2 N_j =$ main effect of interaction of treatment levels; $\beta_3 H_j^2$ e $\beta_4 N_j^2 =$ curvature effects; $\beta_5 H_j N_j$ = effects of interactions; $\varepsilon_j =$ error. From the response surface obtained, it was possible to estimate by partial derivatives $(N_{ideal} = \frac{\partial GP}{\partial N}$ e $H_{ideal} = \frac{\partial GP}{\partial H})$ the ideal dose of the hydrogel and nitrogen combination in each system and year of cultivation. For these determinations, the Genes computational program was used.

## RESULTS AND DISCUSSION

In Figure 1, of pluviometric precipitation and maximum temperature in the oat crop cycle, was observed in 2014, cumulative rainfall of 952 mm (Figure 1A) and, in 2015, 817 mm (Figure 1B). These volumes are close to the historical average of the last 20 years (900 mm), but with different precipitation distribution between the years of cultivation. In 2014, lower rainfall periods occurred at the beginning of the crop cycle and higher maximum temperatures. This condition favors losses of nitrogen fertilization by volatilization and reduces the stimuli to the production of new tines, a component directly linked to grain productivity. From the middle of the cycle until near maturation (2014), rainfall volumes were more expressive, which favored long periods of less sunshine, consequently reducing the efficiency of photosynthesis. In 2015, the highest volume of rainfall occured from the emergency until close to 35 days of oat development, and with maximum temperatures lower than those recorded in 2014. These conditions favor the maintenance of soil moisture increasing the efficiency of nitrogen use by the plant. In addition, from mid-cycle to maturation, rainfall volumes were better distributed and with lower intensity, improving oat development conditions, justifying the higher grain productivity obtained in 2015.

Agriculture is the productive sector most affected by weather variations, since environmental conditions are decisive in increasing productivity (Da Cunha *et al.*, 2015). The temperature and precipitation affect the decomposition rate of the waste in contact with the ground and act on the nitrogen use efficiency by the plant (Acosta *et al.*, 2014). Arenhardt *et al.* (2006) stress that long periods of rainfall in the cycle reduce the efficiency of light and nutrient utilization to photosynthesis, interfering with the development, productivity and quality of grains during the harvest (Castro *et al.*, 2012). The temperature is also decisive to the elaboration of productivity, acting as a catalyst of biological processes, which is why plants require a minimum and maximum temperature for normal physiological activities (Guarienti *et al.*, 2004; Baldiga Tonin *et al*, 2014.).

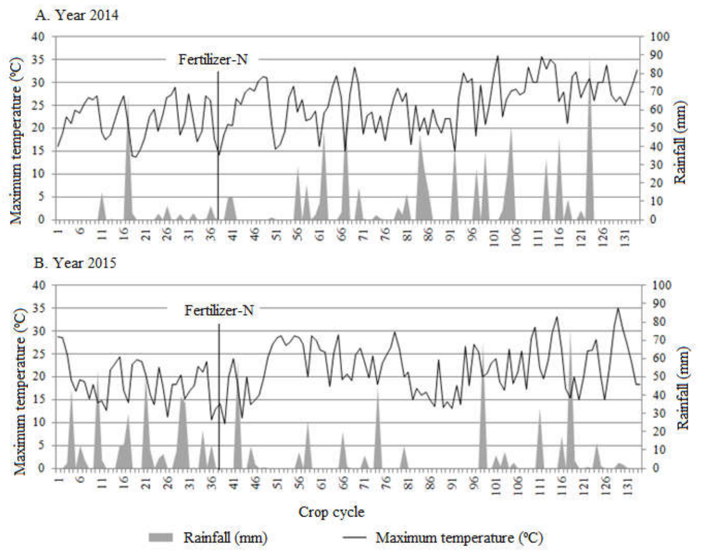


**Figure 1. Rainfall and maximum temperature in the oat cycle**

**Table 1. Average grain productivity in oats under nitrogen and hydrogel levels in soy/oats and soy/corn systems**

| Hydrogel (kg ha$^{-1}$) | Nitrogen (kg ha$^{-1}$) | Soy/oat system | | Corn/oat system | |
|---|---|---|---|---|---|
| | | 2014 | 2015 | 2014 | 2015 |
| 0 | 0 | 1999 f | 2442 g | 1239 i | 1863 h |
| | 30 | 2748 c | 3321 e | 2163 f | 2789 d |
| | 60 | 2875 b | 3810 b | 2468 e | 3337 b |
| | 120 | 2640 c | 3745 b | 2780 c | 3407 b |
| 30 | 0 | 2172 e | 2482 g | 1239 i | 1766 h |
| | 30 | 2894 b | 3319 e | 2264 f | 2758 d |
| | 60 | 2970 a | 3996 a | 2657 d | 3302 b |
| | 120 | 3065 a | 3868 b | 3027 b | 3669 a |
| 60 | 0 | 2036 f | 2847 f | 1593 h | 2189 f |
| | 30 | 2783 b | 3493 d | 1989 g | 2572 e |
| | 60 | 2948 a | 4057 a | 2531 e | 3143 c |
| | 120 | 2615 c | 3677 c | 3237 a | 3627 a |
| 120 | 0 | 2000 f | 2141 h | 1295 i | 1973 g |
| | 30 | 2485 d | 3452 d | 2008 g | 2718 d |
| | 60 | 2786 b | 3644 c | 2427 e | 3087 c |
| | 120 | 2807 b | 3591 c | 3072 b | 3608 a |

Averages followed by the same letters constitute a statistically homogeneous group by the Skott-Knott test with a 5% probability of error.

In oat, the favorable climate is described as the one with milder temperatures and the radiation quality to favor the tillering and filling of grains, without occurrence of rains in great quantity and intensity, although it favors the adequate supply of moisture stored in the soil (Valério *et al*., 2009; Castro *et al*., 2012). In the analysis of the variation source year, nitrogen and hydrogel doses, the main and interaction effects were significant (data not presented). Therefore, tables were shown in order to unfold the effects of this interaction. In Table 1, the average system in soy/oat 2014, higher grain productivity was obtained in the combinations of hydrogel/nitrogen at 30/60 kg ha$^{-1}$, 30/120 kg ha$^{-1}$ and 60/60 kg ha$^{-1}$, respectively. In 2015, hydrogel/nitrogen at 30/60 kg ha$^{-1}$ and 60/60 kg ha$^{-1}$, combinations, respectively, also showed a higher productivity expression in soybean/oats system. Therefore, they are combinations that present greater effectiveness in the efficiency of nitrogen use in this succession system, regardless of agricultural year. In the corn/oat system in 2014 (Table 1), the largest grain productivity was obtained with the hydrogel/nitrogen combination of 60/120 kg ha$^{-1}$, respectively. This combination also favored a higher grain productivity in 2015, although the hydrogel/nitrogen combinations of 30/120 kg ha $^{-1}$ and 120/120 kg ha $^{-1}$ have also shown similar behavior. These results raise the hypothesis of the feasibility of hydrogel use on the higher nitrogen efficiency to the elaboration of grains. In addition, there are combinations which are better adjusted according to the succession system. In the corn/oat system, in 2014, only the hydrogel/nitrogen combination of 60/120 kg ha$^{-1}$, respectively, showed higher grain productivity. In 2015, the hydrogel doses of 30, 60 and 120 kg ha $^{-1}$ showed the best combination with a higher dose of nitrogen. In terms of costs, the biopolymer dose of 30 and 60 kg ha $^{-1}$, was sufficient to promote improvements in the grain productivity expression.

Not always is the use of high levels of nitrogen the most appropriate, and depending on the succession system and meteorological conditions, it is not fully used in the productivity increase (Benin *et al*., 2012. The climatic conditions can alter the efficiency use of this nutrient, resulting in losses by leach in rainy years or volatization in dry years (Acosta *et al*., 2014 Arenhardt *et al*. 2015). Therefore, new technologies are required to improve nitrogen efficiency in grain productivity (Mantai *et al*., 2015, Silva *et al*., 2015). In this context, the use of water-retentive biopolymers can be an alternative to improve nutrient absorption efficiency by maintaining soil moisture (Marques *et al*., 2013). Azevedo (2008), studying the polymer efficiency added to the substrate in coffee, showed that the height and the dry weight of plants increased with the addition of the biopolymer, lengthening the intervals between irrigations.

**Table 2. Regression equation and its parameters in the estimation of hydrogel and nitrogen optimal dose and grain productivity (GP) in culture systems**

| Hydrogel (kg ha$^{-1}$) | Nitrogen (kg ha$^{-1}$) | GP= $b_0 \pm b_1 x \pm b_2 x^2$ | P ($b_i x^n$) | Ideal Dose (kg ha$^{-1}$) | $GP_E$ (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| | | soy/oat system | | | |
| | | 2014 | | | |
| 0 | - | $2036 + 25{,}51x - 0{,}17x^2$ | * | 75 | 2993 |
| 30 | - | $2224 + 21{,}5x - 0{,}15x^2$ | * | 73 | 3180 |
| 60 | - | $2066 + 26{,}88x - 0{,}19x^2$ | * | 71 | 3017 |
| 120 | - | $1998 + 21{,}9 - 0{,}13x^2$ | * | 84 | 2859 |
| - | 0 | $2030 + 2{,}6478x - 0{,}0264x^2$ | * | 50 | 2100 |
| - | 30 | $2767 + 4{,}19x - 0{,}0523x^2$ | * | 40 | 2846 |
| - | 60 | $2880 + 3{,}4723x - 0{,}0347x^2$ | * | 50 | 2851 |
| - | 120 | $2741 + 2{,}2863x - 0{,}0168x^2$ | * | 68 | 2818 |
| | | 2015 | | | |
| 0 | - | $2445 + 34{,}9x - 0{,}2x^2$ | * | 87 | 3968 |
| 30 | - | $2454 + 37{,}71x - 0{,}22x^2$ | * | 86 | 4070 |
| 60 | - | $2813 + 31{,}88x - 0{,}2x^2$ | * | 80 | 4084 |
| 120 | - | $2220 + 41{,}57x - 0{,}25x^2$ | * | 83 | 3949 |
| - | 0 | $2375 + 13{,}0989x - 0{,}1239x^2$ | * | 53 | 2721 |
| - | 30 | $3295 + 3{,}5319x - 0{,}018x^2$ | ns | - | - |
| - | 60 | $3805 + 9{,}4168x - 0{,}0895x^2$ | * | 53 | 4053 |
| - | 120 | $3778 + 0{,}5221x - 0{,}0181x^2$ | ns | - | - |
| | | corn/oat system | | | |
| | | 2014 | | | |
| 0 | - | $1281 + 29{,}49x - 0{,}14x^2$ | * | 105 | 2892 |
| 30 | - | $1278 + 33{,}55x - 0{,}16x^2$ | * | 105 | 3097 |
| 60 | - | $1610 + 13{,}85x$ | * | - | - |
| 120 | - | $1451 + 14{,}27x$ | * | - | - |
| - | 0 | $1182 + 8{,}8361x - 0{,}06311x^2$ | * | 70 | 1485 |
| - | 30 | $2198 - 1{,}785x$ | ns | - | - |
| - | 60 | $2498 + 3{,}7439x - 0{,}0374x^2$ | * | 50 | 2578 |
| - | 120 | $2766 + 12{,}2469x - 0{,}0816x^2$ | * | 75 | 3232 |
| | | 2015 | | | |
| 0 | - | $1900 + 36x - 0{,}2x^2$ | * | 90 | 3520 |
| 30 | - | $1815 + 35{,}8x - 0{,}17x^2$ | * | 105 | 3700 |
| 60 | - | $2245 + 12{,}13x$ | * | - | - |
| 120 | - | $2166 + 12{,}95x$ | * | - | - |
| - | 0 | $1791 + 6{,}7664x - 0{,}0421x^2$ | * | 80 | 2062 |
| - | 30 | $2747 - 0{,}727x$ | ns | - | - |
| - | 60 | $3333 - 2{,}228x$ | * | - | - |
| - | 120 | $3434 + 6{,}808x - 0{,}0452x^2$ | * | 75 | 3690 |

$P(b_i x^n)$ = probability slope parameter; * = significant at 5% probability of error by test t; ns= not significant at 5% probability of error by t test; $GP_E$ = estimated grain productivity.

**Table 3. Sum of squares of the parameters of the response surface model in combined use of nitrogen and hydrogel to the productivity of oats in the crop systems**

| Variable | DF | 2014 | | 2015 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|---|
| | | SQ | R² | SQ | R² | SQ | R² | SQ | R² |
| | | soy/oat system | | | | corn/oat system | | | |
| H | 1 | 79860376 | 35 | 133415117 | 35 | 63190950 | 34 | 101297532 | 35 |
| H² | 1 | 16044522 | 7 | 26793182 | 7 | 8295909 | 4 | 11872563 | 4 |
| N | 1 | 112942650 | 50 | 209030659 | 55 | 135475576 | 72 | 187442205 | 65 |
| N² | 1 | 28316216 | 12 | 48829011 | 13 | 12604457 | 7 | 23144512 | 8 |
| HN | 1 | 19897768 | 9 | 32880785 | 9 | 7675148 | 4 | 18049052 | 6 |
| H²N | 1 | 23523653 | 10 | 38544570 | 10 | 9789711 | 5 | 19161304 | 7 |
| HN² | 1 | 24094834 | 11 | 35650118 | 9 | 11470618 | 6 | 21724363 | 8 |
| H²N² | 1 | 1519783 | 1 | 2813712 | 1 | 1322001 | 1 | 2620824 | 1 |

DF = degrees of freedom; SQ = Sum of squares; $R^2$ = determination coefficient (%); H = hydrogel (kg ha$^{-1}$); N = nitrogen (kg ha$^{-1}$).

In canola, Moghadam *et al*. (2011) concluded that the use of the biopolymer increased the water storage capacity of the soil, lengthening the vegetative period of plants and favoring oil quality. In the search for approximation of the ideal dose of nitrogen and hydrogel (Table 2), the polynomial equations that describe the behavior of the treatments in isolation are presented. In 2014 and 2015, in the soy/oat system, the nitrogen doses at each hydrogel point showed a quadratic behavior. It is noteworthy that the N-fertilizer optimal doses ranged from 71 to 84 kg ha$^{-1}$ in 2014, and from 80 to 87 kg ha$^{-1}$ in 2015. The hydrogel use condition of 60 kg ha$^{-1}$ was the one that most reduced the need to use N-fertilizer with grain productivity similar to other doses.

In 2015, the increase of the ideal nitrogen doses resulted in higher grain productivity, showing that the improvement of the weather during the crop cycle (Figure 1) allows a better use of fertilizer. Hydrogel use in each N fertilizer point in soy/oat system in 2014 (Table 2) showed quadratic behavior, while the ideal biopolymer dose has varied from 40 kg ha$^{-1}$ to 68 kg ha$^{-1}$. On the other hand, in 2015, the equations with N-fertilizer doses of 30 and 120 kg ha$^{-1}$ did not increase grain productivity by biopolymer use. However, nitrogen conditions of 0 and 60 kg ha$^{-1}$ showed optimal hydrogel doses with 53 kg ha$^{-1}$, in a grain productivity expectation of 2721 and 4053 kg ha$^{-1}$, respectively. In the corn/oat system, in 2014 (Table 2), the nitrogen doses at each hydrogel point showed quadratic

**Table 4. Sum of squares of the structure of the response surface model in combined use of nitrogen and hydrogel to the productivity of oat grains in cropping systems**

| n | Structural Model / Response Surface | DF | 2014 | | 2015 | |
|---|---|---|---|---|---|---|
| | | | SQ | $R^2$ | SQ | $R^2$ |
| | | soy/oat system | | | | |
| 1 | $GP = a+bH$ | 1 | 79860376 | 35 | 133415117 | 35 |
| 2 | $GP = a+bN$ | 1 | 112942650 | 50 | 209030659 | 55 |
| 3 | $GP = a+bH+cN$ | 2 | 140194178 | 62 | 250547077 | 65 |
| 4 | $GP = a+bH+cH^2+dN$ | 3 | 156238700 | 69 | 277340259 | 72 |
| 5 | $GP = a+bH+cN+dN^2$ | 3 | 168510394 | 74 | 299376088 | 78 |
| 6 | $GP = a+bH+cH^2+dN+eN^2$ | 4 | 178695629 | 79 | 316235460 | 82 |
| 7 | $GP = a+bH+cN+dHN$ | 3 | 160091946 | 71 | 283427862 | 74 |
| 8 | $GP = a+bH+cH^2+dN+eHN$ | 4 | 170020448 | 75 | 300059745 | 78 |
| 9 | $GP = a+bH+cN+dN^2+eHN$ | 4 | 180303976 | 80 | 318590807 | 83 |
| 10 | $GP = a+bH+cH^2+dN+eN^2+fHN$ | 5 | 187150931 | 83 | 329967354 | 86 |
| 11 | $GP = a+bH+cH^2+dN+eN^2+fHN+gH^2N$ | 6 | 192034047 | 85 | 337920658 | 88 |
| 12 | $GP = a+bH+cH^2+dN+eN^2+fHN+gHN^2$ | 6 | 192605229 | 85 | 335026206 | 87 |
| 13 | $GP = a+bH+ cH^2+dN+eN^2+fHN+gH^2N+hHN^2$ | 7 | 196351895 | 87 | 341587486 | 89 |
| 14 | $GP = a+bH+cH^2+dN+eN^2+fHN+gH^2N+hHN^2+iH^2N^2$ | 8 | 197871679 | 87 | 344401198 | 90 |
| | | corn/oat system | | | | |
| 1 | $GP = a+bH$ | 1 | 63190950 | 34 | 101297532 | 35 |
| 2 | $GP = a+bN$ | 1 | 135475576 | 72 | 187442205 | 65 |
| 3 | $GP = a+bH+cN$ | 2 | 149335073 | 80 | 214006540 | 75 |
| 4 | $GP = a+bH+cH^2+dN$ | 3 | 157630982 | 84 | 225879104 | 79 |
| 5 | $GP = a+bH+cN+dN^2$ | 3 | 161939531 | 86 | 237151052 | 83 |
| 6 | $GP = a+bH+cH^2+dN+eN^2$ | 4 | 167414330 | 89 | 244480550 | 85 |
| 7 | $GP = a+bH+cN+dHN$ | 3 | 157010221 | 84 | 232055592 | 81 |
| 8 | $GP = a+bH+cH^2+dN+eHN$ | 4 | 162571176 | 87 | 238938628 | 83 |
| 9 | $GP = a+bH+cN+dN^2+eHN$ | 4 | 166270038 | 89 | 248207577 | 86 |
| 10 | $GP = a+bH+cH^2+dN+eN^2+fHN$ | 5 | 170263110 | 91 | 252806250 | 88 |
| 11 | $GP = a+bH+cH^2+dN+eN^2+fHN+gH^2N$ | 6 | 171729242 | 92 | 256312356 | 89 |
| 12 | $GP = a+bH+cH^2+dN+eN^2+fHN+gHN^2$ | 6 | 173410149 | 92 | 258875415 | 90 |
| 13 | $GP = a+bH+ cH^2+dN+eN^2+fHN+gH^2N+hHN^2$ | 7 | 174408102 | 93 | 261370934 | 91 |
| 14 | $GP = a+bH+cH^2+dN+eN^2+fHN+gH^2N+hHN^2+iH^2N^2$ | 8 | 175730103 | 94 | 263991758 | 92 |

DF = degrees of freedom; SQ = sum of squares; $R^2$ = determination coefficient (%); H = hydrogel (kg $ha^{-1}$); N = nitrogen (kg $ha^{-1}$); GP = grains productivity (kg $ha^{-1}$); a, b, c, d, e, f, g, h, i = regression coefficients; n = number of the structural model.

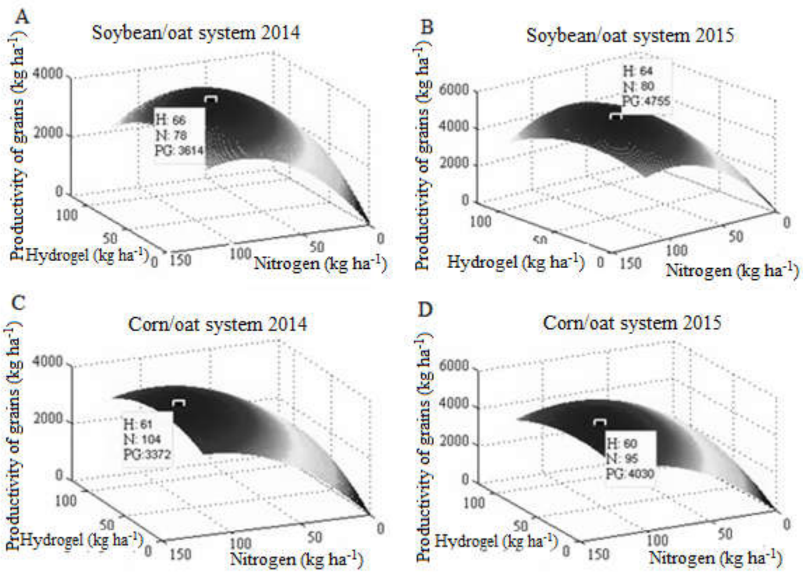


**Figure 2. Response surfaces of hydrogel and nitrogen optimization, of combined use in year conditions and succession**

behavior of biopolymer at 0 and 30 kg $ha^{-1}$, with optimum fertilizer doses of 105 kg $ha^{-1}$ for both conditions. In 2015, hydrogel use of 0 and 30 kg $ha^{-1}$ showed optimal N-fertilizer doses with 90 to 105 kg $ha^{-1}$, respectively. At hydrogel doses of 60 and 120 kg $ha^{-1}$, the increasing behavior of grain productivity through nitrogen was linear, regardless of the crop year. The linearity obtained suggests that biopolymer doses tested promote better use of N-fertilizer, increasing the productivity of oat grains. In corn/oat system, in 2014 (Table 2), N-fertilizer points of 0, 60 and 120 kg $ha^{-1}$ indicated quadratic behavior equations of productivity by the use of hydrogel with optimal doses of biopolymer between 50 and 75 kg $ha^{-1}$. In 2015, only nitrogen doses of 0 to 120 kg $ha^{-1}$ presented a quadratic behavior of productivity by the hydrogel use, with the biopolymer ideal doses of 80 and 75 kg $ha^{-1}$, respectively. At the N-fertilizer dose of 30 kg $ha^{-1}$ in both crop years, the increase of the hydrogel dose was not effective in increasing grain productivity. In addition, the nitrogen dose of 60 kg $ha^{-1}$ in 2015 caused a decrease in grain productivity by increasing hydrogel doses. The use of polymers has favored the cultivation of different species of plants by the storage of water in the soil with its incorporation into the culture. Satisfactory results have already been observed in the formation of coffee seedlings (Azevedo *et al.*, 2008), of “Cleopatra” mandarin rootstock (Cruz *et al.*, 2008), and in the production of Pinus seedlings (Maldonado-Benitez *et al.*, 2011), among other forest species. In lettuce cultivation, the irrigation intervals were decreased, and consequently responsible for 12% in water saving (Mendonça *et al.*, 2015). These results have demonstrated that polymers application can result in a significant reduction in the frequency of required irrigation, besides improving crop productivity. Thus, new management techniques can improve the nitrogen fertilizer efficiency and their effects on productivity (Prando *et al.*, 2013; Brezolin *et al.*, 2016). In this perspective, the use of biopolymers can be an alternative to improve the efficiency of nutrient absorption (Marques *et al.*, 2013). In rye, hydrogel use has promoted a significant increase in the biomass production at different levels of fertilization in water-restricted contexts (Nissen and Tapia, 1996). In grown wheat, hydrogel use has provided higher nitrogen concentration in the grains and in severe water deficit (Geesing and Schmidhalter, 2004). In canola, biopolymer use increased the water storage capacity of the soil, favoring the vegetative period and the quality of oil in grains (Moghadam *et al.*, 2011). Marques *et al.* (2012), in sugar cane cultivation, identified that polymer use at 53.3 kg $ha^{-1}$ in furrow planting contributed to a smaller productivity decrease, highlighting that polymer use may be beneficial in successive cultivation cycles.

Table 3 shows the determination coefficients and the sum of squares in the response surface structure for the construction of a simulation model of oat grain productivity in the combination of hydrogel (H) and nitrogen (N). The determination coefficients have indicated a higher contribution of the nitrogen and hydrogel variables in the response surface structure. Nitrogen shows greater contribution in the simulation model of grain productivity. The quadratic variables combined ($H^2N^2$) showed little influence on the surface structure. The coefficient of determination or explanation $R^2$ quantifies the adjustment quality, because it provides a measure of the variation proportion explained by the regression equation regarding the total variation of responses (Santos *et al*, 2008; Rodrigues and Iemma, 2009).
Table 4 presents the structural models of response surfaces in the systems and years of cultivation. The model proposed for the simulation is number 10, because it has a simpler structure, a determination coefficient similar to the more complex ones, and it brings the nitrogen and hydrogel in an isolated form of grade 1 (H; N) and grade 2 ($H^2$, $N^2$) and combined with grade 1 (HN). Thus, the chosen model presents the necessary data for partial derivation in the calculation of the combined optimal point.

The response surface models developed for grain productivity simulation per crop year in the succession systems were:

**soy/oat system**

$$PG_{2014} = 39{,}433 + 38{,}607H - 0{,}193H^2 + 58{,}624N - 0{,}305N^2 - 0{,}165HN \quad (1)$$

$$PG_{2015} = 11{,}119 + 48{,}707H - 0{,}248H^2 + 78{,}552N - 0{,}403N^2 - 0{,}21HN \quad (2)$$

**corn/oat system**

$$PG_{2014} = 6{,}846 + 27{,}929H - 0{,}147H^2 + 48{,}308N - 0{,}204N^2 - 0{,}096HN \quad (3)$$

$$PG_{2015} = 20{,}525 + 34{,}625H - 0{,}158H^2 + 62{,}134N - 0{,}274N^2 - 0{,}163HN \quad (4)$$

In the simulation of the ideal dose of hydrogel and nitrogen combination by the response surface model, we made the deduction through the partial derivative of grain productivity as a function of hydrogel ($\frac{\partial GP}{\partial H}$) and nitrogen ($\frac{\partial GP}{\partial N}$). Thus, as shown in Figure 2 (1), in the soy/oat system in 2014, the optimum dose of hydrogel and nitrogen was 66 kg $ha^{-1}$ and 78 kg $ha^{-1}$, respectively, at an expected grain productivity of 3614 kg $ha^{-1}$. In 2015 (Figure 2B), the hydrogel and nitrogen optimum combination was 64 kg $ha^{-1}$ and 80 kg $ha^{-1}$, respectively, with an oat grain productivity estimate of 4755 kg $ha^{-1}$. In Figure 2C, in corn/oat system in 2014, the optimum hydrogel and nitrogen doses were 61 kg $ha^{-1}$ and 104 kg $ha^{-1}$, respectively, at an expected grain productivity of 3358 kg $ha^{-1}$. In 2015 (Figure 2D), the ideal combination of hydrogel and nitrogen was 60 kg $ha^{-1}$ and 95 kg $ha^{-1}$, respectively, with expected productivity of 4030 kg $ha^{-1}$.

In the soy/oat system (Figure 2), simulation of grain productivity by the hydrogel and nitrogen optimum dose, has indicated greater favoring of expression in 2015, a fact also observed in the corn/oat system. Although the values of hydrogel optimum dose were similar per system and year of cultivation, nitrogen optimum dose for grain preparation was substantially changed, condition that strengthens the literature reports on the great instability of the nutrient in real conditions of cultivation. In addition, the most unfavorable year (2014) showed higher nitrogen use with lower grain productivity in the corn/oat system. Although in soy/oat system, the optimum nutrient dose was similar between the years, there was a decrease in grain productivity in 2014. However, it is possible to verify that the use of response surface analysis represented an optimization method that qualifies the understanding of agricultural processes in the search for validation of more sustainable and efficient technologies in cropping systems.

The use of planning associated to response surface analysis has been used in researches that seek to optimize products and processes, aiming at minimizing costs and time and maximizing productivity and quality (Rodrigues and Iemma, 2009). Busato *et al.* (2014), through response surface analysis, obtained alternative fungal control methods in laboratory. Ferreira *et al.* (2015), through this methodology, obtained higher efficiency of the live weight ratio of broiler chickens in relation to food consumption and food conversion. Schumacher, *et al.* (2013), obtained ideal doses combined through the response surface, of nitrogen and phosphorus, seeking the maximum growth of black acacia. In corn, Silva *et al.* (2014) have found optimal doses of nitrogen and phosphorus, 70 and 120 kg $ha^{-1}$, respectively, focused on maximum grain productivity. Because it is an innovative technology, of little use on a large scale, the hydrogel kilogram is high-priced, with an approximate value of R$ 18,00. Taking into account the average optimal dose of biopolymer in this study (62,7 kg $ha^{-1}$), the product cost would be R$ 1130,00 per hectare. On the other hand, it is a product of hydroretentor action in the soil with duration of 3 to 4 years, favoring the crops in succession. Therefore, costs will be diluted throughout the agricultural crops.

In addition, the validation of scientific results could enable its use on a large scale, further reducing the cost of the hydro-retentor product. Studies by Hurtado *et al*. (2007), in the production of Gladíolos flowers, have observed a greater retention of the nitrogen fertilizer and micronutrient to the soil with the use of biopolymers, reducing nutrient leaching. Nevertheless, we highlight the innovative character of this study due to the technology of hydrogel use in real conditions of cultivation aimed at greater efficiency of nitrogen use to the elaboration of oat grains, a species of great importance to animal and human feeding.

**Conclusion**

The use of different doses of the hydroabsorbent biopolymer associated to the nitrogenous fertilization in the cover influences positively on the productivity of oat grains, regardless of year and succession system. The adjusted dose of hydrogel and nitrogen at the maximum grain productivity in the soy/oat system is around 65 and 80 kg $ha^{-1}$, respectively, and in the corn/oat system, 60 and 100 kg $ha^{-1}$ respectively, regardless of cultivation year.

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