Effects of fertigation on corrosion in galvanized steel used in center pivot systems

Karina V. Rodrigues, Luiz A. Lima and Michael S. Thebaldi

ABSTRACT

One of the main causes of agricultural equipment deterioration is corrosion. In center pivot irrigation systems, deterioration mainly occurs in galvanized steel pipelines. Fertigation can increase corrosion because fertilizers become corrosive when exposed to water or moisture; this corrosion reduces the service lifetime of the equipment. In this study, fertigation-induced corrosion was evaluated in specimens of galvanized steel (similar to that used in center pivot systems), simulating 10 years of operation comprising 5 fertigations per year with a duration of 7 hours each. Immersion tests were performed in solutions containing 0, 5 and 10 g/L fertilizer concentrations to obtain the mass loss per unit area of the metallic material, which increased in response to increases in both the exposure time in the corrosive environment and the fertilizer concentration. The results showed that fertigation increases corrosion in galvanized steel and the higher fertilizer concentration leads to a higher corrosion, since, for the same exposure time, the mass loss for the 10 g/L solution was 43% greater than the 5 g/L.

Key words | exposure time, galvanized steel, immersion test, irrigation water quality, mass loss, zinc coating

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INTRODUCTION

The use of mechanized irrigation systems has grown in recent years. According to the WBCSD (2014), by 2050, irrigated agriculture on 16% of the total cultivated area will be producing approximately 44% of the world's food. According to Frizzone *et al.* (2018), worldwide, in total 35 million hectares are irrigated by sprinkler irrigation systems, with the center pivot system representing 23% of this area. In addition, Wood (2019) presents that the center pivot market is expected to grow by 15.8% by 2026.

According to the manufacturer Valley, the expected lifetime of galvanized steel pipelines used in center pivots is approximately 25 years, although degradation problems have been reported after less than 10 years of use. These degradation problems occur due to the high number of annual operation hours, the quality of the irrigation water and the supply of fertilizers via irrigation (Valley 2016).

The corrosion potential can increase significantly with some factors (e.g. solution pH, dissolved oxygen and chloride ion concentration, temperature), which are often related to the presence of oxides, hydroxides and carbonates formed by the reaction of irrigation water with fertilizers (Nwoye *et al.* 2014).

Fertigation is the application of fertilizers, soil amendments, or other water-soluble products through an irrigation system. The use of fertigation can increase corrosion in galvanized steel pipelines because fertilizers become corrosive when exposed to water or moisture (Oki & Anawe 2015). In center pivot irrigation systems, corrosion can decrease equipment efficiency, cause irrigation water contamination, leaks and reduce system lifetime, leading to increased operational costs due to maintenance and equipment replacement (Eker & Yuksel 2005).

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Each fertilizer has its corrosivity level, which is determined by the reaction between the environment and the metallic surface, reactions that generate ammonia or hydrogen sulfide being the most aggressive. For example, ammonium nitrates or sulfates cause material degradation by decreasing the pH of the solution. Therefore, the proportion of desirable nutrients in the crop may alter the degree of corrosiveness of the solution. It is believed that the effects are most apparent in solutions containing about 15% nitrogen, especially when it is derived partly from urea and ammonium nitrate (Oki & Anawe 2015).

One of the most economical forms of protection against corrosion is the use of galvanized steel, which has a zinc coating layer that protects the steel substrate by preventing exposure to corrosive environments and by galvanic protection (Marder 2000; Della Rovere *et al.* 2013).

Corrosion is one of the main causes of spare parts installation and equipment replacement in agricultural operations (Eker & Yuksel 2005). However, few studies have examined the causes or quantitatively assessed this phenomenon (e.g. Eker & Yuksel 2005; Della Rovere *et al.* 2013; Oki & Anawe 2015).

Thus, this study evaluated the fertigation-induced corrosion in specimens of galvanized steel (similar to that used in center pivot irrigation systems) after 10 years of simulated exposure to solutions with different fertilizer concentrations.

METHODS

The experiment was conducted at the Laboratory of Irrigation in the Department of Water Resources and Sanitation at the Federal University of Lavras (Universidade Federal de Lavras – UFLA), where three 1,000 L water tanks were installed, each individually equipped with a 0.5 hp single-phase pump (model SFP-35, Somar).

The solution recirculation pipe network was constructed from 32 mm solvent weld PVC pipes and fittings. The experimental apparatus is shown in Figure 1.

The test involved simulating 10 years of fertigation in a center pivot system, assuming 5 fertigations per year with a duration of 7 hours each, leading to 50 events in approximately 10 years. The fertigation solution was composed of 20-0-20 NPK fertilizer (20% nitrogen from urea, 0% phosphorus and 20% potassium oxide (K_2O) obtained from a white potassium chloride source) in two concentrations: 5 and 10 g/L. A solution without fertilizer addition was also tested (control, 0 g/L). The solutions were prepared with UFLA's supply water, and each water tank was filled with 500 L of solution.

To compare the effects of corrosion under these three treatments, galvanized steel specimens were manufactured from the same material as the center pivot pipelines. The specimens were washers with 32-mm external diameter, 13-mm internal diameter and 3-mm thickness, which were provided by Valmont, a Brazilian subsidiary of Valley that manufactures center pivots.

The specimens were held inside the tanks with the aid of PVC pipes and nylon strings to ensure that they were set at an intermediate depth and that they did not collide with each other.

In the fertigation simulation, 21 specimens were used for each simulated year, wherein 7 specimens were used for each concentration, totaling 210 samples over the 10 simulated years. The test was performed in terms of cumulative hours, and at the end of each cycle, the specimens were removed from the tanks for analysis.

The mass loss in the metallic material was analyzed via immersion corrosion tests, which were conducted following a procedure adapted from the American Society for Testing Materials (ASTM) standard G-31 (ASTM 2004), in which the specimens are immersed for set time intervals in the solutions. After each simulation year, the washers were removed for mass loss analysis.

After removing the specimens from the immersion, they were dried for one hour at 65 °C in a forced circulation oven (MA 035, Marconi) located at the Laboratory of Soil Physics Analysis, Department of Water Resources and Sanitation, UFLA. Immediately after drying, the specimens were weighed on a Scientech SA 210 precision scale.

The mass loss per unit area of the specimens was calculated by the difference between the initial and final weight of the specimen divided by the surface area exposed to the solution.

For the statistical analysis, a 3×10 factorial design with 7 replications was used, and an analysis of variance (ANOVA) was performed using the F-test. In the case of a

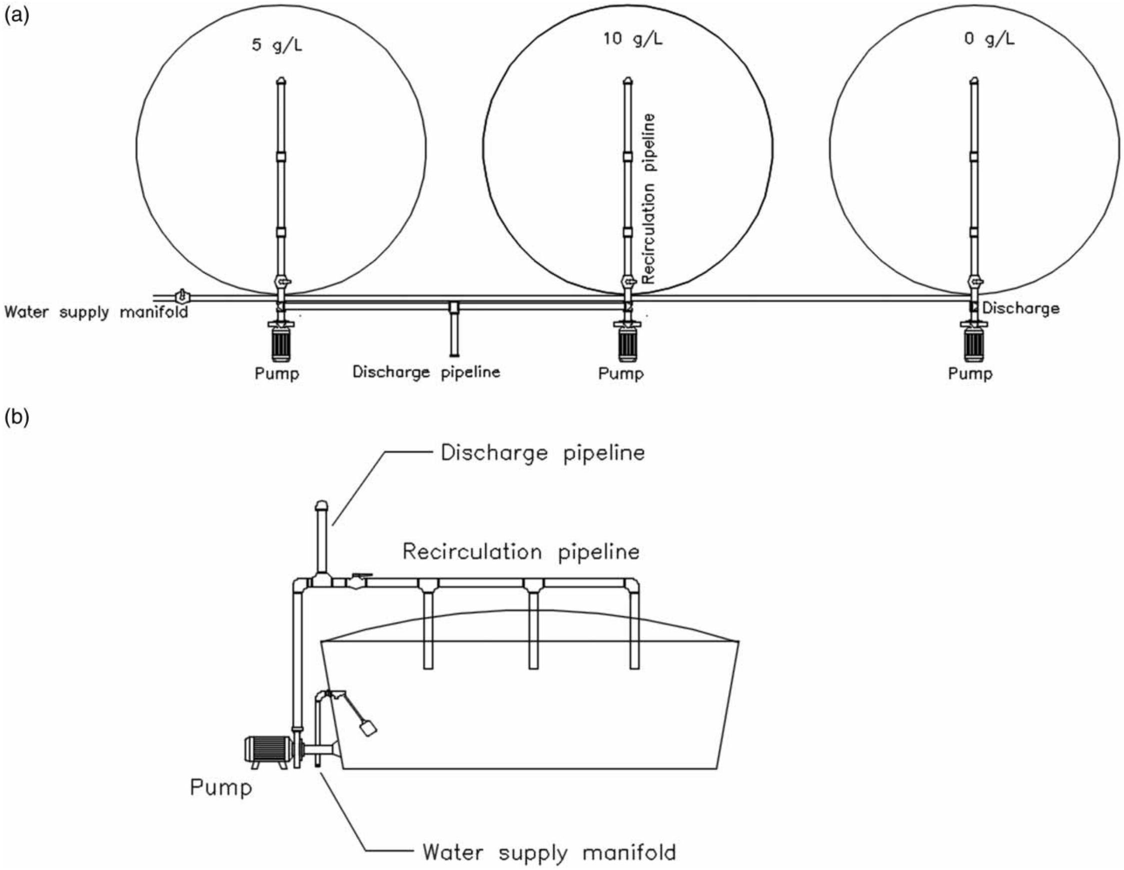

Figure 1 | Experimental apparatus. (a) plan; (b) side view.

source of significant variation in the F-test, the mean mass loss of each fertilizer concentration was compared by the Scott–Knott test at a 5% probability (Scott & Knott 1974). A regression analysis was used to test the effect of exposure time on mass loss. Statistical analyses were performed with the statistical software AgroEstat version 1.1 (Barbosa & Maldonado Júnior 2015).

RESULTS AND DISCUSSION

The ANOVA for the mass loss per unit area in the galvanized steel specimens caused by exposure to solutions with different fertilizer concentrations is summarized in Table 1.

The fertilizer concentration, exposure time and the interactions between them had significant effects on the mass loss per unit area by F-Test, as shown in Table 1, thus, Table 2 shows the simple effect of the concentration variation by comparing the mean mass loss per unit area for each concentration. The 10 g/L concentration caused the greatest mass loss, followed by the 5 g/L concentration, which resulted in approximately 57% of the mass loss

Table 1 | Summary table of the ANOVA evaluating the mass loss in galvanized steel specimens subjected to different 20-0-20 fertilizer concentrations for different exposure times

Cause of variation	DF	Mean square and F significance for mass loss
Concentration (C)	2	0.00003303*
Time (T)	9	0.00000481*
C × T	18	0.00000145*
Residual	180	0.000000257
Total	209	–
Coefficient of variation	57.44287	

DF indicates degree of freedom and * indicates significant by the F-test at a 5% probability.

Table 2 | Comparison between the mass loss per unit area in galvanized steel specimens exposed to solutions with different 20-0-20 fertilizer concentrations

Concentration (g/L)	Mass loss (mg/cm²)
10	1.566 a
5	0.893 b
0	0.192 c

Values followed by the same lowercase letter do not differ significantly by the Scott–Knott test at 5% probability.

observed from exposure to the 10 g/L concentration. The solution without fertilizer addition (0 g/L) had the lowest mass loss by a considerable margin.

The results in this study corroborate those obtained by Eker & Yuksel (2005), in which the decrease in the coating thickness of the galvanized steel caused by corrosion was considerably lower in solutions without fertilizer addition.

The simple effect of the exposure time on the specimens' mass loss is shown in Figure 2. The behavior of this effect was best represented by a linear mathematical model indicating that the longer the exposure time was, the greater the mass loss per unit area. This behavior was similar to the results obtained by Suzumura & Nakamura (2004) and Diler *et al.* (2014), in which the mass loss caused by corrosion in galvanized steel and zinc alloys increased with increasing exposure time in a corrosive environment.

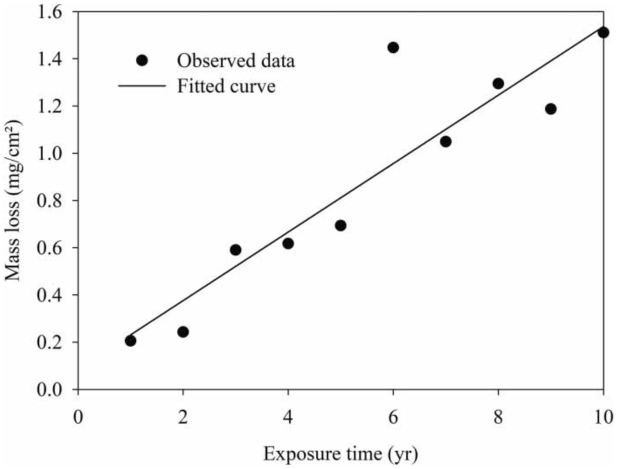

Figure 2 | Effect of the exposure time on galvanized steel specimens' mass loss due to the use of fertigation solutions.

Table 3 shows the mass loss of the specimens and the corresponding interaction between the sources of variation.

Table 3 shows that there was a significant difference in the mass loss per area starting in the third year of simulated fertigation, and after the fifth year, the mass loss per unit area values differed significantly among the three individually analyzed concentrations.

Figure 3 shows the effect of exposure time on the mass loss per unit area of the specimens in each of the 20-0-20 fertilizer concentrations. Note that the specimen mass loss values increase as the exposure time in the corrosive environment increases, except for the solution without fertilizer addition (0 g/L). In addition to this general increasing mass loss trend, there was also a considerable increase in the sixth-year mass loss for the 5 and 10 g/L concentrations, followed by a decrease, and in the following years, the mass loss continued to increase, although in a less drastic manner.

The peak mass loss that occurred in the sixth year can be explained by the considerable increase in solid particle deposition on the specimens, wherein the mass of these particles was added to the mass of the specimens; thus, the specimen mass values decreased after the simulation.

Furthermore, the corrosion products that formed on the surface of the specimens starting in year six may have acted as a protective film of zinc oxide, protecting the specimens from corrosion. Nwoye *et al.* (2014) also observed a decrease

Table 3 | Effect of fertilizer concentration in each fertigation cycle on mass loss of galvanized steel specimens

		Mass loss (mg/cm²)		
Fertigation cycle (yr)	Exposure time (h)	0 g/L	5 g/L	10 g/L
1	35	0.094 a	0.280 a	0.243 a
2	70	0.090 a	0.281 a	0.356 a
3	105	0.135 b	0.869 a	0.767 a
4	140	0.193 b	0.435 b	1.222 a
5	175	0.267 b	0.552 b	1.263 a
6	210	0.229 c	1.373 b	2.740 a
7	245	0.237 c	0.928 b	1.982 a
8	280	0.239 c	1.371 b	2.273 a
9	315	0.211 c	1.268 b	2.081 a
10	350	0.226 c	1.574 b	2.731 a

Values followed by the same lowercase letters in the same row are not significantly different according to the Scott–Knott test at a 5% significance level.

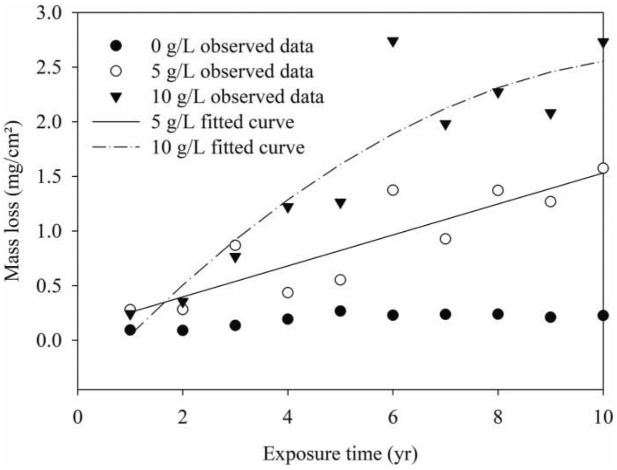

Figure 3 | Effect of the exposure time for each fertigation solution concentration on mass loss of galvanized steel specimens.

in the corrosion of galvanized steel after 50% of the maximum exposure time in the corrosive environment. The authors attributed this to the possible formation of a protective film that became more adherent at this time. When it occurs, there is also a decrease in oxygen diffusion, which decelerates the corrosion rate (Sun *et al.* 2013; Nwoye *et al.* 2014).

The equations that best mathematically describe the mass loss per unit area behavior as a function of the simulated fertigation time for each of the fertilizer concentrations studied are shown in Table 4.

For the solution without fertilizer addition, the effect of exposure time on mass loss per unit area was not significant. For the 5 g/L concentration, the effect of exposure time on mass loss per unit area was described by a linear equation with an R^2 of 77.31%. For the concentration of 10 g/L, the effect of exposure time on mass loss per unit area was described by a quadratic equation with an R^2 of 85.56%.

As long as the experimental essays were carried out, the quality variables of the solutions were monitored, where the 5 g/L solution obtained electrical conductivity values between 4.56 and 4.69 dS/m and for the 10 g/L solution, 8.66–8.81 dS/m. In addition, total solids concentrations were approximately 3 and 6 g/L, for the 5 and 10 g/L concentrations, respectively (Ayers & Westcot 1994). The pH was also measured, being verified at an average value of 6.2 for both solutions. The average temperature of the solutions during the experiment was between 17 and 25 °C.

Table 4 | Fitted equations for the effect of the exposure time in the solutions with 5 and 10 g/l concentrations of 20-0-20 fertilizer

	Equation	R^2
5 g/L	ML = 1.14E-04 + 1.417E-04ET	0.7731
10 g/L	ML = −4.45E-04 + 5.25E-04ET − 2.25E-05ET^2	0.8546

R^2, coefficient of determination; ML, mass loss and ET, exposure time.

According to NBR 12212 Standard proposed by the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas – ABNT 1992), waters with concentrations of total dissolved solids higher than 1 g/L are considered corrosive. Thus, the solutions containing 5 and 10 g/L of 20-0-20 fertilizer are typically corrosive, causing greater deterioration in galvanized steel and consequently causing a greater loss of metallic material from the specimens, as observed in this study.

The corrosion process cannot be eliminated, but can be minimized by adopting some anti-corrosion practices, such as modification of the metal composition itself or of its surface (such as the use of coatings) or changing the corrosion potential of the aqueous environment with the use of cathodic protection (Palanisamy 2019).

In fertigation it is difficult to predict the magnitude of corrosion as the corrosivity potential of fertilizers varies with the nutrient type and the in-solution substances combination. According to Roffey (2015) nitrogen and phosphate fertilizers are prone to slow corrosion when in contact with steel, so they can be used more often in fertigation, while ammonia-based products had higher corrosive potential.

CONCLUSIONS

Due to its advantages to the agricultural production chain, fertigation should be performed, however, as this study shows, nutrient solutions most often increase corrosion in galvanized steel pipes such as those used in center pivots. Therefore, the behavior of these solutions with this system should be investigated to help growers extend the life of their equipment while exploiting their maximum capacity.

Based on the results obtained in this study, the mass loss per unit area increases in response to increases in both the fertilizer concentration and the exposure time between the metal surface and the solution. Thus, solutions with lower fertilizer concentrations and applied over shorter time intervals should preferably be used to ensure a lower corrosive effect on galvanized steel pipes.

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