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Effect of urea ammonium nitrogen fertilizer on corrosion of different metals

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Abstract
Corrosion rate helps in understanding the vulnerability of metals to corrosion. An experiment was conducted to investigate the effect of liquid fertilizer (Urea Ammonium Nitrate) with different dissolution ratio with water on the corrosion rate of different metals. Three dissolution ratios of UAN and water viz. 1:0, 1: 5 and 1:10 were used for corrosion treatment. Metal coupons of three metallurgies- stainless steel (SS), mild steel (C1010 grade) and mild steel (commercial) were used for the study. The corrosion coupons were fully suspended in the fertilizer solutions inside the airtight glass jars. Metal corrosion coupons started corroding within 24 hours. The metal coupons were weighed after 281, 681 and 1025 h. The average corrosion rates were 0.55 mm per year and 0.311 mmy^{-1} for MS (Commercial) and MS C1010, respectively.

Keywords: corrosion rate, metal coupons, Urea ammonium nitrate, fertilizer

Introduction
Many commercial chemicals used in farming, including fertilizers, grain and silage preservatives, chemicals for pest, disease and weed control. Farm wastes and slurries are also significantly corrosive. The chemicals are most frequently responsible for damaging farming structures and machinery. The extent of corrosion of a metal depends on its local environment; behaviour in the atmosphere, in permanently wet conditions, and in the soil, is different, and metals and protective treatments must be chosen accordingly. In general, the components of fertilizer solutions are similar to those employed in solid fertilizer (Palgrave and Smith, 1972) [8].

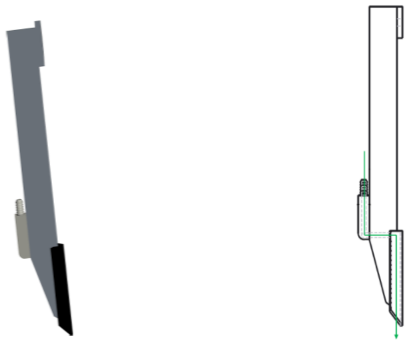
Some fertilizers are more corrosive than others, especially if they decompose or react to produce aggressive substances such as ammonia or hydrogen sulfide. The most widely used nitrogen-based liquid fertilizer in the USA and the European Union is Urea Ammonium Nitrate (UAN) (Anonymous 2017a) [1] which is an aqueous solution of urea and ammonium nitrate. UAN solutions are commonly injected into the soil beneath the surface, sprayed onto the soil surface, dribbled as a band onto the surface, added to irrigation water, or sprayed onto plant leaves as a source of foliar nutrition (IPNI 2019) [6]. UAN contains nitrogen (N) between 28 to 32 percent. Cahoon (2002) [4] reported that UAN is corrosive to metals and during the initial investigation, corrosion of shank material was observed within 24 hours of UAN contact. The relative ratios of the essential plant nutrients influenced the corrosiveness of compound liquid fertilizers (Table 1). There is some evidence that the greatest effects occur with fertilizer solutions containing about 15% nitrogen, especially when half the free nitrogen is derived from urea and half from ammonium nitrate (Anonymous 2017b) [2].

Table 1: Corrosive reaction of liquid fertilizers

Liquid fertilizers	Chemicals	Reactions with steel
Nitrogenous solutions	Ammonium nitrate, urea	Slow reaction with steel; can be more rapid at welds and bolt holes.
Phosphate solutions	Ammonium phosphate	Tends to be less reactive; forms a protective phosphate coat which can protect the metal from subsequent attack by nitrogenous solutions, unless acid conditions prevail.

Source: Anonymous 2017b [2].

This study was carried out during the design and development of liquid fertilizer applicator operated by a tractor. Liquid fertilizer had to be injected or placed inside the soil with the help of furrow opener. The purpose of the furrow opener was to cut open the soil and placed the liquid fertilizer in the sub-soil. After that the seed had to be placed at shallow depth. A prototype furrow opener was designed with a hole drilled in the centre across the width of the shank (Fig. 1a & b). The purpose was to use the hole inside shank as a conduit to pass the liquid fertilizer. Hence, it was deemed necessary to understand the corrosion behaviour of liquid fertilizer (UAN) towards different metals.



(a) (b)

Fig 1: (a) Furrow opener prototype and (b) direction of flow of liquid fertilizer

Materials and Methods

Preparation of coupon specimen for corrosion test

Metal coupons of three metallurgies-stainless steel (SS S304), mild steel (C1010) and mild steel (commercial grade, C) were used for the study in the form of strip style coupons (Fig. 2). The mechanical properties of the coupons are listed in Table 2. Cleanflow® India Pvt. Ltd, New Delhi provided the SS and MS coupons. The mild steel (commercial grade, C) coupon was prepared in the workshop of the Division of Agricultural Engineering, IARI, New Delhi.

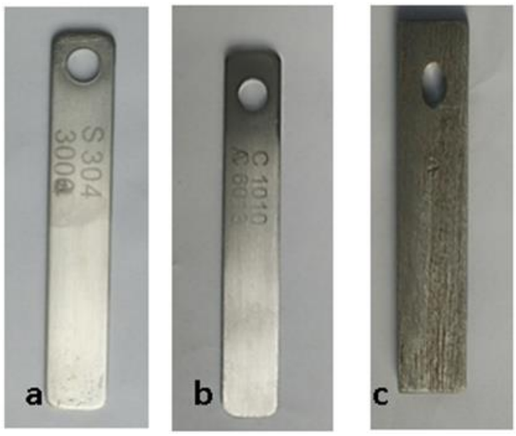


Fig 2: Metal coupons a) stainless steel b) Mild steel (C1010) and c) Mild Steel (C)

Table 2: Metal coupon element content/mechanical properties

Chemical composition	Corrosion Coupon Grades		
	MS C1010*	**SS S304***	**MS Commercial Grade (C)****
Fe (%)	99.18-99.62	66-74	98.36
C (%)	0.08	0.08	0.09
Cr (%)	-	18	<0.005
Mn (%)	0.30-0.60	Max 2	0.53
Ni (%)	-	8-10.5	0.44
P (%)	<0.04	Max 0.045	0.075
S (%)	<0.05	Max 0.03	0.028
Si (%)	-	Max 1	0.274
Mechanical Properties			
Hardness Brinell (HB)	105	125	207.67

*Standard specification

**Coupon material was tested at farm machinery testing centre, CCS HAU, Hisar

An experiment was planned with different selected corrosion coupons to investigate the effect of UAN fertilizer with different UAN: Water ratio on corrosion rate (Table 3).

Table 3: Plan of an experiment for measuring the corrosion rate

S. No.	Independent parameters	Levels	Details	Dependent parameters
1.	Metal type	3	M_1 = Stainless steel M_2 = Mild steel (C1010 grade) M_3 = Mild steel (Commercial grade)	Corrosion rate after 281, 681, 1025 hours
2.	UAN: Water concentration	3	U_1=1:0 U_2=1:5 U_3=1:10	

The coupons were fully suspended in the fertilizer solution inside the jar with the help of a PVC thread (Fig. 3) and water in three ratios viz. 1:0, 1: 5 and 1:10. Metal corrosion coupons started corroding within 24 hours. The metal coupons were weighed after 281, 681 and 1025 h. The metal coupons were carefully taken out of the jar and were cleaned and dried before weighing. Subsequently, metal loss, as well as corrosion rate, were determined. Corrosion takes place due to oxidation of the iron present in the metal. Due to oxidation, the corrosion coupon gained weight known as scaling. Hence, descaling was an important unit operation before measuring weight loss and corrosion rate over time.

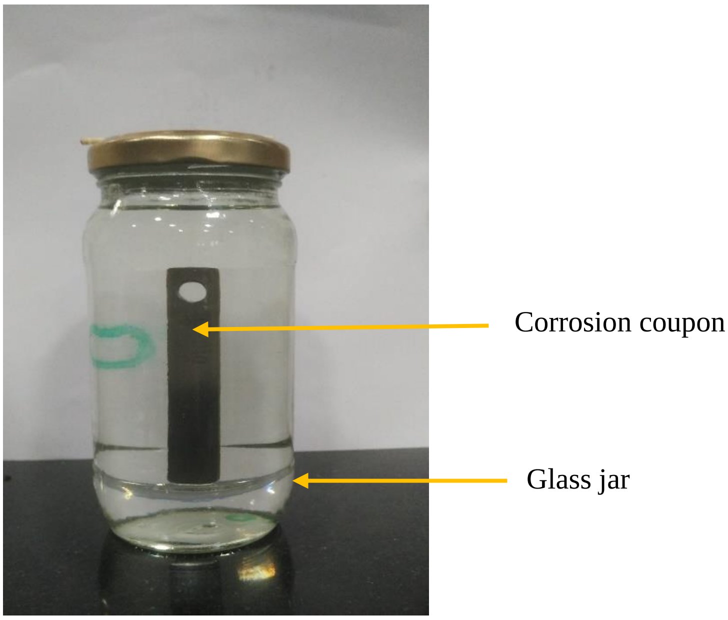


Fig 3: Metal Corrosion coupon dipped in UAN: Water solution in a glass jar

Corrosion rate

Corrosion rate (CR), helps in understanding the vulnerability of metals to corrosion. It was measured by the gravimetric method. The corrosion rate of the metal was measured by exposing the sample to the test medium and loss of weight of the material was measured as a function of time. The coupons were weighed with electronic balance before the start of the experiment. UAN fertilizer in the different ratio was filled in a 200 ml glass jar. All the glass jars were tightly closed and kept in an ambient environment for the study. The data of weight loss of coupons was recorded after 281 h, 681 h and 1025 hours. The coupons were scaled due to oxidation by oxygen present in the UAN solutions. The method given by IS13643, 1993 [7], was used to clean/descale the coupons before weighing. The corrosion coupons were chemically washed in a blend of Hydrochloric acid (HCl) and water. After cleaning coupons, they were placed in an oven at 70°C for 15 minutes to dry. After drying, the coupons were weighed using a Mettle Toledo weighing balance (New Classic ML 503, Switzerland). The corrosion rate was calculated assuming uniform corrosion over the entire surface of the coupons. The corrosion rate was expressed in mm per year of metal degraded and was calculated from the weight loss using the formula (Gezawa *et al.*, 2015) [5]:

$$\text{Corrosion Rate (CR)} = \frac{k \times \Delta W}{A \times T \times \rho}$$

Where,

CR = Corrosion rate in mm/yr,

K = Constant for unit conversion (8.76×10^4)

ΔW = weight loss in g,

= (weight at the beginning of the test -weight at the end of the test)

A = Exposed surface area of Coupon cm^2,

T = Time of exposure in hours,

P = Density of mild steel g/cm^3

Results and Discussion

Metal coupons were submerged fully in the different solution of UAN and water in three ratios viz. 1:0, 1: 5 and 1:10. Metal corrosion coupons started corroding within 24 hours (Fig. 4).

Fig 4: Corrosive effect of UAN: Water on different metals after 24 hrs

Effect of UAN concentrations solution on corrosion rate of metal coupons

In general, the corrosion rate decreased with the time of exposure. After 281 h, more corrosion rate was observed than to 641 h and 1025 hours. The corrosion rate of MS coupon C1010 during the initial 281 hours of exposure (Fig. 5) to UAN water solution was within the range of 0.0049-0.6062 mm per year and the same decreased to the level of 0.0108-0.288 mm per year as recorded during time interval of 281-641 hours, Fig. 6. The stainless steel coupon showed no sign of corrosion during the given time interval. The minimum corrosion rate of 0.0133-0.1175 mmy^{-1} was recorded for MS (Commercial) for the exposure duration of 641-1025 hours at different levels of UAN concentrations, Fig. 7. The corrosion effect of UAN water solution concentrations varied significantly for different materials at 5% level of significance. The MS coupon C1010 was more corrosion resistant as compared to MS coupon (Commercial).

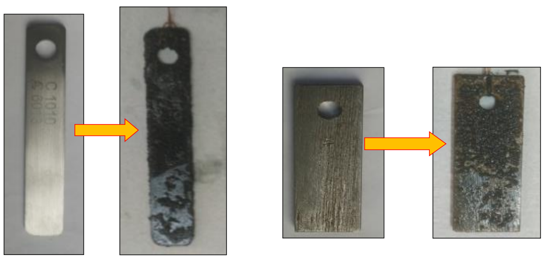


Fig 5: The corrosive effect of UAN: Water on (a) Mild steel (C1010) (b) Mild steel (C) after 281 hrs

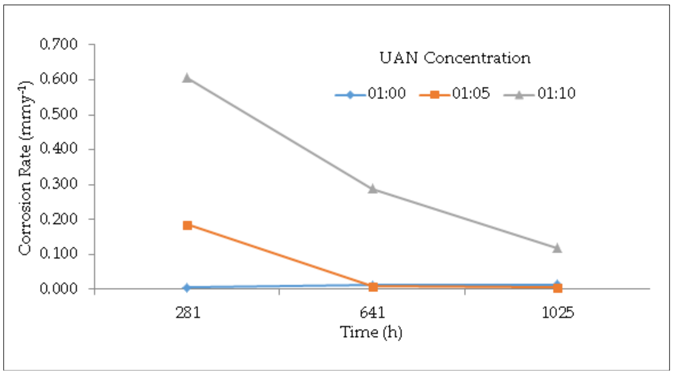


Fig 6: Variation in Corrosion rate of Mild steel C1010 by different UAN concentrations

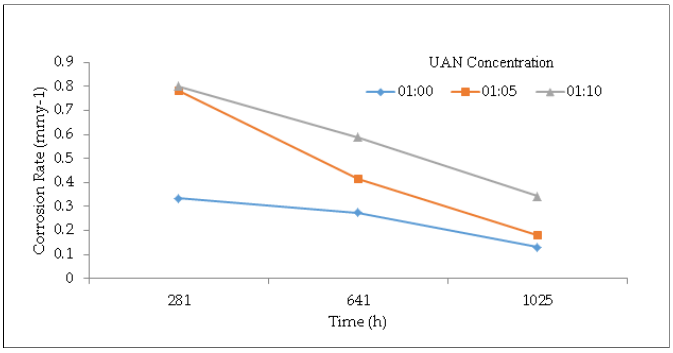


Fig 7: Variation in corrosion rate of mild steel (Commercial) by different UAN concentrations

The best material for the fabrication of furrow opener was stainless steel due to greater corrosive resistance. Whole shank or the lower part of the furrow opener could be made of stainless steel but the same may not be economical, this would be must when UAN fertilizer contact with material is physically unavoidable. Both mild steel (C1010) and mild steel (Commercial) coupons were affected by UAN concentration. However, the metal commercially available showed more corrosion than that of mild steel C1010 coupon. The average corrosion rates were 0.55 mm per year and 0.311 mmy^{-1} for MS (Commercial) and MS C1010, respectively. This implied Mild steel (Commercial) would corrode 1.8 times faster than Mild steel C1010 when in contact of UAN. However, instead of flowing liquid fertilizer through holes inside the mild steel (Commercial) shank, the corrosive effect of UAN was overcome by providing a separate flow path for liquid fertilizer. Delivery pipes made of PVC commonly used in water filtering units were selected to meet the purpose.

Conclusion

UAN concentrations had severe effect on corrosion rate of the mild steel used for fabrication of shovel. The average corrosion rates were 0.55 mm per year and 0.311 mmy^{-1} for MS (Commercial) and MS C1010, respectively. Increase in corrosion rate was due to increased content of water in higher diluted UAN. The increased amount of water increases the amount of hydrogen ion leading to formation of nitric acid (HNO_3). Similar results were obtained by Bureman (2013) [3] who concluded that UAN (28%N) was 20 per cent more corrosive than UAN (30% N) as water content in UAN (28%N) was more than in UAN (30%). Also the rate of corrosion was initially more (0-281 h) and slowly decreased with passage of time. The corrosion rate was found to decrease with the time of exposure. This was due to less availability of hydrogen ion in the solution since most of the H^+ ions were used initially for nitric acid formation. This is in commensurate with the results obtained by Bureman (2013) [3]. In the final design prototype of liquid fertilizer applicator, PVC pipes (6 mm diameter and 2 mm thick) were used for delivery of the UAN fertilizer in order to avoid contact of liquid fertilizer with furrow surface.

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