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Use of controlled-release mustard-coated urea could to reduce nitrogen leaching in onion crop in comparison to conventional and stabilized fertilizers

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Abstract

Urea is the most widely used nitrogen fertilizer and is considered the richest source of nitrogen, containing about 46%. Despite this its efficiency is limited, as nearly 30-35% of applied urea is lost to the environment. Improving its effectiveness requires controlling how nitrogen is released in the soil. Research have shown that slow or controlled released fertilizers help managing the timing and buildup of nitrogen in the soil, thereby enhancing overall nitrogen availability. Regulating the release rate is crucial in reducing nitrogen losses. By slowing the conversion of urea into ammonium for several days, these fertilizers minimize losses that typically occur due to rapid urea breakdown, leaching, or volatilization. In many cases, upto 60% of urea can be lost through these processes, but the use of nitrification inhibitors can significantly reduce such losses. The study was conducted to know the effect of sustained release of Nitrogen from urea coated with mustard extract on the yield parameters of the Onion crop. The basic soil properties of the experimental field were recorded before the commencement of the trial. The pH of the soil with different replications was neutral in reaction, EC was in moderate limits, Organic carbon was in higher range with a mean of 1.08%. Nitrogen and Phosphorous was in moderate to higher range with the mean of 401 and 18.5 kg ha⁻¹ respectively. Potassium was in moderate limits with a mean of 204.30 kg ha⁻¹. The trial was done in continuation for two years and the pooled data showed that the various yield parameters like bulb diameter, Bulb weight, total yield etc. showed a significant enhancement. It was observed that the yield improvement was about 15% as compared to recommended dose of fertilizers.

Keywords: Urea efficiency, nitrogen release, nitrification inhibitors, mustard extract coating

Introduction

The rapid growth of the global population has placed increasing pressure on agriculture to meet rising food demands. For instance, global production of staple crops such as wheat and maize reached 713 and 1018 million metric tons in 2013, and is projected that by 2050, food demand will be about 85% higher in 2013 (Long *et al.*, 2015) [23]. To enhance crop productivity, large quantities of water and fertilizers have been applied. Among nutrients, nitrogen (N) is a key macronutrient, yet its natural availability in soils is often insufficient to support optimal plant growth (Li *et al.*, 2016) [22], leading to heavy reliance on nitrogen fertilizers. Over the period from 1961 to 2013, global nitrogen fertilizer consumption increased dramatically, from 11.3Tg N per year to 107.6 Tg N per year. This rise has been particularly notable in intensive vegetable production systems (Thompson *et al.*, 2020 and Tei *et al.*, 2020) [41, 38]. Conventional fertilizers used by farmers are highly soluble, but they can result in nitrogen losses of upto 70% through volatilization and leaching (Da Costa *et al.*, 2019) [14]. These losses lead to two major problems: reduced fertilizer efficiency as nutrients move away from the root zone and become inaccessible to plants, and environmental damage, including greenhouse gas emissions and water pollution through eutrophication. Nitrogen is commonly applied in the form of nitrate or is rapidly converted into nitrate through microbial nitrification in the soil. However, these processes can also result in losses of nitrogen as ammonia, nitric oxide and other nitrogen oxides, which contribute to greenhouse gas emissions.

Furthermore, nitrate is not strongly retained in soil and is highly prone to leaching, further reducing its availability to plants (Tei *et al.*, 2020 and Da Costa *et al.*, 2019) ^[38, 14].

Nitrogen leaching tends to be more pronounced in intensive greenhouse systems than in open field agriculture, mainly because plant growth is accelerated under controlled conditions and nitrogen fertilization is frequently used as a cost effective way to boost yields (Tei *et al.*, 2020) ^[38]. The environmental consequences of nitrate leaching have become a global concern. In Europe, this issue led to the introduction of the nitrates Directive by the European Council to reduce nitrogen pollution and improve water quality Directive (The European Council, 1991) ^[40]. Under this directive, Nitrate Vulnerable Zones (NVZs) are designated as areas where agricultural drainage water may contaminate larger water bodies with excessive nitrate levels (Massa *et al.*, 2010) ^[27]. Therefore, restricting fertilizer use in agriculture is considered an effective strategy to mitigate nitrate pollution in surface waters (Van Grinstein *et al.*, 2012) ^[45]. Excessive nitrogen application can also result in nitrate accumulation in the edible parts of crops (Wang *et al.*, 2004) ^[47]. Dietary intake of high nitrate levels has been associated with health risks, including gastric cancer (Ahluwalia *et al.*, 2015, Umar *et al.*, 2007 and Zhong *et al.*, 2002) ^[3, 44, 50]. As a precautionary measure, the European Commission has established limits on nitrate concentrations in food to protect consumer health (The European Commission, 2011) ^[39].

In response to these concerns, significant efforts have been directed towards improving nitrogen fertilization practices. One effective strategy is the use of enhanced efficiency fertilizers, which aim to optimize nutrient availability in soils while simultaneously reducing nitrogen losses through leaching and volatilization. Enhanced-efficiency fertilizers are generally classified into three categories (Carson *et al.*, 2012) ^[10]: (i) Slow release fertilizers, (ii) Stabilized fertilizers and (iii) Controlled release fertilizers. Slow release fertilizers consist of nitrogen compounds with low solubility, which become accessible to plants gradually through microbial breakdown. In contrast, controlled released fertilizers are designed with a core shell structure. The inner core typically contains water soluble nutrients such as urea, ammonium nitrate, or potassium nitrate, while the outer coating is made from materials like sulphur, resin based substances (e.g., alkyd or polyurethane), thermoplastic polymers, or inorganic mineral layers (Dubey *et al.*, 2019) ^[15]. Controlled-release fertilizers can also be made by the combination of sulfur-coated urea with an additional polymer or resin coating (Azeem *et al.*, 2014 and Qiao *et al.*, 2016) ^[4, 33]. Two main limitations to the use of controlled-release fertilizers are their relatively high cost, and the difficulty to develop an adequate coating for irregularly shaped fertilizers or highly soluble compounds such as urea. The nutrient released from coated fertilizers operates through an osmotic process, where water diffuses across the coating and dissolves the fertilizer inside. The movement of water through this coating layer is the key factor controlling the release rate. This process is influenced by several factors, including the chemical composition of the polymer, the thickness of the coating, and the surrounding temperature. For a specific coating material and thickness, the rate of nutrient release is therefore largely dependent on temperature conditions, making it important to evaluate performance under different temperature regimes.

As a result, nutrient delivery to the soil can be regulated and predicted over time (Naz, 2016) ^[28]. This study was designed to assess the impact of such controlled release fertilizers on nitrogen leaching, as well as on the yield and quality of onion crops, in comparison with conventional fertilization methods using nitrification inhibitors or readily soluble fertilizers.

Onion (*Allium cepa* L.) is a widely cultivated vegetable grown across diverse climatic regions worldwide. Nitrogen is a vital nutrient for plant growth and is often the primary factor limiting crop yield. It is required in greater quantities than other nutrients, and onions in particular have a high demand for nitrogen compared to many other vegetable crops (Greenwood *et al.*, 1980) ^[13]. However, the efficiency of applied nitrogen fertilizer in onions is relatively low, typically ranging between 30-340% (Greenwood *et al.*, 1980; de Visser *et al.* 1995; Sharma *et al.*, 2012) ^[13, 9, 30] or even less (Halvorson *et al.*, 2002) ^[1]. This poor recovery is mainly due to the shallow root systems of onion plants and the variability in the amount of mineral nitrogen already present in the soil before planting (de Visser *et al.*, 1995; Halvorson *et al.*, 2002; Brewster, 2008) ^[9, 1, 8].

Mustard belongs to the Brassicaceae family and is commonly used in food as a blend of seeds from different species, including *Sinapis alba* (White/Yellow mustard), *Brassica nigra* (Black mustard), and *Brassica juncea* (Brown/oriental mustard). Mustard seeds provide several health benefits due to the presence of bioactive compounds such as isothiocyanates, phenolics, dithiones and dietary fiber. However high levels of erucic acid and glucosinolates in rapeseed and mustard oil limit their suitability as regular cooking oils. Glucosinolates, which are sulphur containing compounds widely found in Brassica species, can also reduce the palatability of rapeseed cake and may lead to nutritional issues in livestock. Although mustard is mainly grown as an oilseed crop, its young leaves are consumed as vegetables and are rich in nutrients such as vitamin A, vitamin C, calcium and iron. Mustard seeds typically contain about 24-40% oil, 17-26% protein and around 19% hull. After oil extraction, the remaining residue known as mustard cake accounts for approximately 60% of the seed. India ranks third globally in mustard cake production, generating about 5.7 million tonnes annually. Mustard is also valued for its preservative qualities, as it helps inhibit the growth of food spoilage microorganisms and extends shelf life due to its antioxidant and antimicrobial activity, while antioxidants like quercetin, catechin, vitamin C and Vitamin E reduce oxidative reductions in food (Reddy and Prasad, 1975) ^[35]. Nitrogen from urea, when applied to soil, can be lost through leaching due to the activity of nitrifying bacteria such as nitrobacter and nitrosomonas, which convert nitrogen into nitrite and then nitrate (Sahrawat, 1981) ^[36]. These forms are highly mobile in soil, leading to significant losses up to 60% through leaching or volatilization. Such losses can be minimized by modifying urea application methods, such as coating or layering the pellets. The use of slow release or controlled release fertilizers particularly coated fertilizers has proven effective in reducing nutrient losses (Cuhra *et al.*, 2011) ^[12]. These fertilizers are produced by covering conventional fertilizer granules with materials that slow their dissolution rate, thereby controlling nutrient release (Bhattacharya *et al.*, 1999) ^[5]. The effectiveness of this process depends on the type of coating material used. Incorporating active

substances like neem oil into the coating can further improve the sustained release of nitrogen from urea. Additionally, compound such as allyl isothiocyanate, derived from mustard and responsible for its pungent taste, can be isolated and utilized as coating agents. The present study was designed to explore the use of mustard by products as a coating material for urea and to evaluate their effects on soil properties and yield parameters in onion cultivation. Experimental plots measuring 3×3 ft were established and crops were grown following standard agronomic practices with ten replications. The onion variety used was Yellow Globe and the recommended fertilizer dose was applied. The soil at the experimental site was characterized as sandy loam.

Materials and Methods

A. Experimental site

Experiment was laid out in the divisional farms of the Division of Soil Science, Faculty of Horticulture, SKUAST-K, Shalimar, using the variety *Yellow Globe*. The seedlings were procured from the Division of the Vegetable Science, SKUAST-K.

B. Treatment details

Urea was selected for the study, and treatments were applied using various combinations. The various treatment combinations are illustrated the table 1 below. The control treatment was taken as reference point, recommended dose of Fertilizers was followed as per the POP (Package of Practices) compiled by the SKUAST-K, which is suitable for the Onion cultivation in the temperate ecosystem. The amended urea was used as a source of Nitrogen. The amount of nitrogen to be utilized for each sub plot was calculated from the standard package of practices for the temperate conditions. The urea pellets were thoroughly mixed with the mustard extract before the application in the field.

C. Observations

Soil samples from all the sub plots of the experimental field were collected up to the depth of 25 cm. after air drying, the soil samples were ground and sieved through a 2 mm mesh. The resulting composite samples were then examined for different physicochemical characteristics. Soil particle size distribution was determined using the International pipette Method as outlined by piper (1996). Bulk density was measured using the core method following Blake and Hartge (1986a) ^[6], while particle density was assessed using the pycnometer method as described by Blake and Hartge (1986b) ^[7]. Porosity was calculated by using formula:

$$\text{Porosity (\%)} = 1 - \frac{\text{Bulk density}}{\text{Particle density}} \times 100$$

Soil pH and electrical conductivity (EC) were measured following standard methods outlined by Jackson (1973) ^[20]. Organic carbon (OC) was estimated using the dichromate oxidation method developed by Walkley and Black (1974) ^[46]. Available nitrogen was analyzed through the alkaline potassium permanganate distillation technique as described by Subbiah and Asija (1956) ^[37]. Soil phosphorous availability was determined by extraction with 0.5 N sodium bicarbonate at pH 8.5, following the method of Olsen *et al.* (1954) ^[29]. Available potassium was extracted using 1N

ammonium acetate at pH 7.0 (Jackson, 1973) ^[20], and its concentration was measured with a flame photometer.

D. Statistical analysis

The experiment was carried out using a randomized block design with three replications. A control treatment was included as a benchmark for comparison. Altogether, nine distinct treatment combinations were tested. Data analysis was performed using the standard agri stat software package, which is available as freeware.

Results and Discussion

During the readings, it was found that soil treated with mustard by product brought the effective changes in soil Physico-chemical properties as evident by the data presented. The soil samples were taken initially before the lay out of the experiment and at the end of the crop cycle. This exercise was followed for both the years of the trial, and the pooled data is presented in the paper. Particle size distribution is a governing factor for assessment of nutrient supplying capacity, aeration and drainage of soils. Many researchers (Francois *et al.*, 2004) suggested that the level and availability of plant nutrients including micronutrients are governed by fineness and coarseness of soil. The soils of all the locations are fine textured attributing to their alluvial nature. The soil texture varied from clay loam to silty clay loam. Dominant textural class of Kashmir soils was observed to be clay loam and silty clay loam by Handoo (1983) ^[18], Ramzan (2013) ^[34] and Wani *et al.* (2010) ^[49] also reported a similar type of findings. Soil reaction, shaped by specific chemical, mineral and biological conditions, influences nutrient availability, toxicity levels, microbial processes and root development. Because both plants and microorganisms are highly sensitive to their chemical surroundings, soil reaction is regarded as one of the most critical chemical properties of the soil solution.

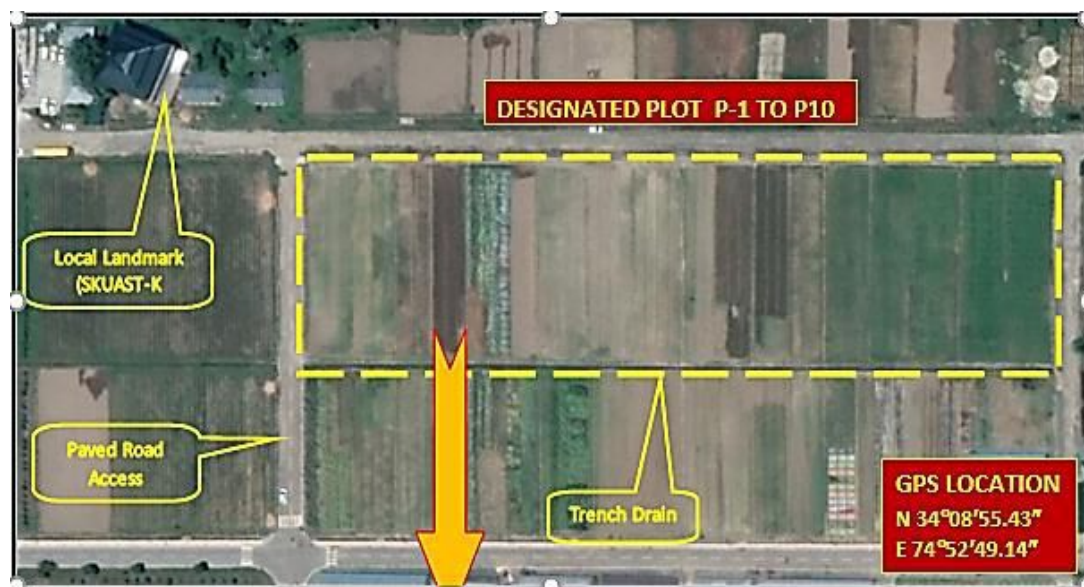
As represented in the Table 3, the pH of the soil ranged from 6.50 to 7.90 with a mean of 7.13. Soil pH was found to be slightly acidic to slightly alkaline. EC higher than the optimum range would mean too high salt concentration, because of overuse of high salt fertilizer or due to lack of drainage (Agriculture Solutions, 2011) ^[2]. As evident from the Table 3 the electrical conductivity in the study area indicated a normal range which is below 1 dSm⁻¹ which is safe for growing any crop. Wani *et al.* (2009) ^[48] also reported the normal range of electrical conductivity while studying soils of Kashmir. The EC ranged from 0.07 to 0.14 dSm⁻¹ with an average of 0.10 dSm⁻¹. The primary estimates of organic carbon in Table 3 indicated significantly higher organic carbon in T₄ (1.33%) which may be due to long term application of organic residues to the soil and also due to organic matter build-up with time. The results are in line with Kumar, B *et al.* (2008) ^[21]. The lowest organic carbon was found in Control plot with no treatment applied (0.79%) with mean value of 1.01%. The organic matter of the soils ranged from 1.35% to 2.28% with an average of 1.75%. The highest organic matter was shown by T₄ (2.28%) which is because of the fact that it is also high in organic carbon. The range of all the primary nutrients like Nitrogen, phosphorous and Potassium were in medium to high array with an average value of 399 kg ha⁻¹, 19 kg ha⁻¹ and 204 kg ha⁻¹ respectively. As far as the yield parameters of Onion were considered, it was seen that considerable improvements were seen in various physiological

characteristics. The plant height showed an increase of 14.9% from the RDF to amended urea use, similarly around same improved efficiency percentage of about 13% was seen for other important physiological parameters like Number of leaves per plant, bulb diameter, neck Diameter,

Fresh Bulb Weight. It was observed that the yield increased about 13% in the plots treated with amended urea as compared to the plots treated with the recommended dose of fertilizers for the onion crop.

Recommended Dose of Fertilizers for the Onion crop under temperate conditions

Manures/Fertilizers	Dose	Remarks
F.Y.M	23-30 (tonnes/ha)	Entire F.Y.M, P and K and ½ N applied before transplanting and ½ N when the seedling have established in the month of March.
Nitrogen	100 kg/ha	
Phosphorous	80 kg/ha	
Potash	60 kg/ha	



Location of the Experimental farm

Experimental Lay out of the treatment and replications under RBD

(Replications-03 Treatments-10)

R ₁ T ₁	R ₂ T ₄	R ₃ T ₂
R ₁ T ₄	R ₂ T ₇	R ₃ T ₆
R ₁ T ₆	R ₂ T ₂	R ₃ T ₉
R ₁ T ₂	R ₂ T ₈	R ₃ T ₄
R ₁ T ₅	R ₂ T ₁	R ₃ T ₈
R ₁ T ₃	R ₂ T ₀	R ₃ T ₀
R ₁ T ₀	R ₂ T ₅	R ₃ T ₅
R ₁ T ₈	R ₂ T ₉	R ₃ T ₇
R ₁ T ₇	R ₂ T ₃	R ₃ T ₃
R ₁ T ₉	R ₂ T ₆	R ₃ T ₁

Table 1: Treatment Details in sub plots of the main Plot.

Treatments	Details
T ₀ (Control)	N = 98 gm P = 144 gm K = 59 gm Mustard Extract-Nil
T ₁	N = 98 gm P = 144 gm K = 59 gm Mustard Extract-0.5 ml/urea used
T ₂	N = 98 gm P = 144 gm K = 59 gm Mustard Extract-0.4 ml/urea used
T ₃	N = 98 gm P = 144 gm K = 59 gm Mustard Extract-0.25 ml/urea used
T ₄	N = 142 gm P = 144 gm K = 59 gm Mustard Extract-0.5 ml/urea used
T ₅	N = 142 gm P = 144 gm K = 59 gm Mustard Extract-0.4 ml/urea used
T ₆	N = 142 gm P = 144 gm K = 59 gm Mustard Extract-0.25 ml/urea used
T ₇	N = 55 gm P = 144 gm K = K = 59 gm Mustard Extract-0.5 ml/urea used
T ₈	N = 55 gm P = 144 gm K = K = 59 gm Mustard Extract-0.4 ml/urea used
T ₉	N = 55 gm P = 144 gm K = K = 59 gm Mustard Extract-0.25 ml/urea used

Table 2: Physical properties of the experimental plot after the application of the amended urea.

Treatments	Texture	Bulk Density	Particle Density	Porosity
T ₀ (Control)	Clay Loam	1.41	2.51	44%
T ₁	Clay Loam	1.23	2.46	50%
T ₂	Clay Loam	1.25	2.49	51%
T ₃	Clay Loam	1.20	2.50	52%
T ₄	Silty Clay Loam	1.21	2.40	51%
T ₅	Clay Loam	1.24	2.45	50%
T ₆	Clay Loam	1.22	2.49	51%
T ₇	Silty Clay Loam	1.26	2.50	50%
T ₈	Clay Loam	1.25	2.45	51%
T ₉	Silty Clay Loam	1.24	2.44	51%

Table 3: Chemical properties of the experimental plot after the application of the amended urea.

Treatments	pH	EC	Organic Carbon	Organic Matter	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)
T ₀ (Control)	7.31	0.12	0.87	1.49	370	22	184
T ₁	7.42	0.09	0.97	1.66	396	17	212
T ₂	6.95	0.10	0.79	1.35	372	21	192
T ₃	7.12	0.07	1.12	1.92	410	16	190
T ₄	6.88	0.14	1.33	2.28	433	24	233
T ₅	6.50	0.12	0.93	1.59	392	18	165
T ₆	7.90	0.13	1.17	2.01	421	23	213
T ₇	7.48	0.11	1.14	1.96	418	14	221
T ₈	6.71	0.11	0.96	1.65	382	19	213
T ₉	7.10	0.10	0.90	1.54	396	17	220
Mean	7.13	0.10	1.01	1.75	399	19	204

Table 4: Plant physiological properties of the onion (*cv yellow Globe*) at the end of the experiment (pooled data for two years).

Observations Treatments	Plant Height (cm)	No. Of Leaves	Bulb Dia. (cm)	Neck Dia. (cm)	Fresh Bulb Weight (grams)	Yield/ha (tons)
Control	42.36	8.22	3.01	9.55	125.04	9.22
RDF	52.96	13.00	5.88	13.94	145.91	14.43
Amended Urea	60.90	15.00	6.76	16.03	167.80	16.59

Conclusion

Nutrient efficiency of urea can be managed by using the coating methodology. Although there are several chemical nitrification inhibitors which are presently available but still the capability of natural or botanical by-products can be tested as nitrification inhibitors for the slow release of nitrogen. Which could possibly help in reducing the leaching losses of the nitrates and in turn the water pollution caused by them. In our study, it was found that the different treatments of the mustard coated urea can be used for inhibiting the nitrate leaching loss in the vegetable crops like onion. In addition to having the inhibiting nature, the various physico chemical properties of soils were also enhanced which contributed to the overall yield increase of the crop.

Declaration of competing interest

The authors state that they have no known financial conflicts or personal relationships that could have influenced the work presented in this paper.

Ethics declarations

Not applicable.

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