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# EFFECT OF DIFFERENT NITROGEN SOURCES AND NITRIFICATION INHIBITORS ON PRODUCTIVITY AND QUALITY OF POTATO (*Solanum tuberosum* L.)

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## ABSTRACT

Two field experiments were carried out at a private farm (Kafr Alam, Meniat el-Nasr), Dakahlia Governorate, during winter seasons of 2008/09 and 2009/10, to study the effect of different sources of nitrogen fertilization, i.e., ammonium nitrate (AN), ammonium sulphate (AS) and urea (U) as soluble form of nitrogen with or without nitrification inhibitors dicyandiamide (DCD) as well as ureaform (UF), sulpher coated urea (SCU), isobutylidene diurea (IBDU) , polyolefin-coated urea (PCU) and compost as slow-release N-sources on productivity and quality of potato cv. Diamant.

The obtained results revealed that N-sources differed significantly in all studied characters. Application of PCU had more plant height, fresh and dry weights per plant, total tuber yield and marketable yield, followed by IBDU in both seasons. Moreover, PCU and IBDU had significant higher dry matter, specific gravity, NPK-uptake, and starch content in comparison with other treatments. Meanwhile, application in urea as a soluble form gave the highest reducing sugars compared with other treatments. On the other hand, nitrate and nitrite content of potato tubers in treatment amended with AN at 180 kg fed$^{-1}$ was higher than with other treatments in the two seasons.

This study suggests that slow release N fertilizers, e.g., polyolefin-coated urea and isobutylidene diurea at 135 kg N fed$^{-1}$ are the most effective treatments for high productivity, quality and net profit of potato fields with keeping the health and safety of human and environment.

**Keywords:** Potato, nitrogen sources, soluble form, slow-release, productivity.

## INTRODUCTION

One of the foremost management priorities in potato cropping systems is nitrogen (N) (Stark *et al*., 2004). Typically, nitrogen is the most limiting nutrient in crop production and is found in higher concentrations than all other mineral nutrients in plants (Ludwick *et al*., 2002). Potatoes are especially sensitive to N nutrition. Studies show a steady, but not excessive, supply of N is important for maximum tuber yield, size, and solids, as well as minimal internal and external defects (Taysom *et al*., 2007).

Some of the N not used by the crop is presumed lost through denitrification, runoff, volatilization, and leaching. Such losses raise concerns about water contamination. Low use efficiency of fertilizer N also reduces economic returns from fertilizer inputs. Nitrogen-use efficiency can be improved by reducing N losses (Englesjord *et al*., 1997). New fertilizer products – controlled-release N fertilizers or CRN – that release N at controlled rates to maintain maximum growth and minimize losses has been developed in the last two decades (Goertz, 1991). Increased efficiency can also increase yield and quality of crops and economic return for growers.

Controlled-release fertilizers (CRFs) may be one such alternative that may improve N recovery by the crop, thereby minimizing excessive $NO_3$ leaching. Nitrogen release from traditional products, such as sulfur-coated has been unpredictable (Trenkel, 1997). Recently, improved CRFs have been developed with polymer coating technology to modify the rate and duration of nutrient release.

Polymer-coated CRFs can improve N use efficiency and productivity of potato (Taysom *et al*., 2007) and decrease $NO_3$ leaching (Wang and Alva, 1996). Zvomuya *et al*. (2003) reported higher potato yields for PCU compared with urea, but effects on N leaching and NRE were not evaluated.

In another study, Hutchinson and Simonne (2003) demonstrated that N rates can be reduced with a controlled-release fertilizer program compared to a soluble N fertilizer program (non-coated urea and/or ammonium nitrate) without reducing crop yield or quality. Also, Pack (2004) found that all six controlled release fertilizers (CRF) with the 168 kg N $ha^{-1}$ rate, potatoes gave 3 to 14 % higher marketable yield than the AN at the rate of 224 kg N $ha^{-1}$. Also at the rate of 224 kg N $ha^{-1}$, five CRFs produced 7 to 36% higher marketable yield than with the AN.

Nitrification inhibitors are compounds that delay bacterial oxidation of the ammonium-ion ($NH4^+$) by depressing over a certain period of time the activities of *Nitrosomonas* bacteria in the soil. They are responsible for the transformation of ammonium into nitrite ($NO_2^-$) which is further changed into nitrate ($NO_3^-$) by *Nitrobacter* and *Nitrosolobus* bacteria. The objective of using nitrification inhibitors is, therefore, to control leaching of nitrate by keeping nitrogen in the ammonia form longer, to prevent denitrification of nitrate-N and to increase the efficiency of nitrogen applied (Trenkel, 1997). Nitrification inhibitors may reduce loss of fertilizer N from the root zone by reducing leaching and denitrification. This reduced N loss should be reflected in increased crop yields (Martin, *et al*., 1993).

Dachler (1993) found that potatoes showed clear positive effects in yield, tuber size and starch-yield and economically higher proceeds with the use of ammonium-sulfate-nitrate (ASN) + nitrification inhibitor (DCD) compared with ammonium-nitrate-lime (ANL) with or without DCD. Amberger (1989) mentioned that nitrification inhibitor, dicyandiamide (DCD), reduced nitrate leaching and increased yields and N uptake of potato plants. Shoji *et al*. (2001) found that use of controlled release fertilizer (polyolefin coated urea) and/or nitrification inhibitor (dicyandiamide) to conserve air and water quality are basically due to maximizing nitrogen use efficiency (NUE), reducing the N fertilization rate and gave maximum tuber yields under center-pivot irrigated potato grown in a sandy field. Vallejo *et al*. (2006) reported that nitrification inhibitor dicyandiamide (DCD) inhibited nitrification rates and reduced $N_2O$ and NO emissions from pig slurry by at least 83% and 77%, respectively.

Therefore, the objectives of this research were to investigate the influence of different N-sources (soluble or slow release form) and nitrification inhibitor on productivity and quality of potato plants.

## MATERIALS AND METHODS

Two field experiments were conducted at a private farm (Kafr Alam, Meniat el-Nasr), Dakahlia Governorate, during winter seasons of 2008/09 and 2009/10, to study the effect of slow release-N (Ureaform (UF), sulpher coated urea (SCU), isobutylidene diurea (IBDU), polyolefin-coated urea (PCU) and compost) and soluble-N (ammonium nitrate "AN", ammonium sulphate "AS" and urea "U") fertilizer with or without nitrification inhibitor dicyandiamide (DCD) on productivity, and quality of potato cv. Diamant. Seed tubers were planted on 15th of October in both seasons of study. Plot area was 11.25 $m^2$; consisted of 3 ridges; 5 m long; 75 cm wide, and 25 cm apart.

The soil type under study was clay loam, with the mechanical and chemical analysis as shown in the following Table (1) according to Page (1982).

**Table 1: Some physical and chemical properties of the experimental soil.**

| Physical properties | Value | | Chemical properties | Value | |
|---|---|---|---|---|---|
| | 1st season | 2nd season | | 1st season | 2nd season |
| Sand (%) | 25.8 | 25.1 | pH value | 7.9 | 7.8 |
| Silt (%) | 33.2 | 33.7 | EC $dSm^{-}1$(in soil paste) | 0.8 | 0.8 |
| Clay (%) | 41.0 | 41.2 | Total N (%) | 0.04 | 0.05 |
| Texture class | Clay-loam | Clay-loam | Available P (ppm) | 13.5 | 12.8 |
| $CaCO_3$ | 3.0 | 3.1 | Available K (ppm) | 380 | 346 |
| Organic matter (%) | 1.4 | 1.6 | | | |

A complete randomized blocks design with three replicates was used. The experiment included 11 treatments, which were as follows:

1. Ammonium nitrate, AN (33.5 % N); (Control).
2. Ammonium sulphate, AS (20.5% N).
3. Urea, U (46.0 % N).
4. Compost, (1.2 % N).
5. AN + nitrification inhibitor dicyandiamide (DCD).
6. AS + DCD.
7. U + DCD.
8. Ureaform, UF (36.2 % N).
9. Sulfur coated urea, SCU (32.0 % N).
10. Isobutylidene diurea IBDU (32.0 % N).
11. Polyolefin-coated urea PCU (38.0% N).

Single superphosphate (15.5% $P_2O_5$) was added once during soil preparation at the rate of 75 kg $P_2O_5$ $fed^{-1}$. Potassium sulphate (48% $K_2O$) was used in two equal doses with the 2nd and 3rd doses of ammonium nitrate at the rate of 96 kg $K_2O$ $fed^{-1}$.

AN, AS and U (soluble form) at the rate of 180 kg N $fed^{-1}$ was added at three equal doses, i. e. the first after emergence, and second and third doses were applied with 2nd and 3rd irrigation, respectively. Slow release N-fertilizers, i. e., UF, SCU, IBDU, PCU at the rate of 135 kg N fed$^{-1}$ and compost at the rate of 18 ton fed$^{-1}$; as fresh weight (moisture =21.7%) were added during soil preparation with superphosphate amendment. Nitrification inhibitor DCD mixed with N-soluble form was applied at the rate of 5% of added N. Other agricultural practices were carried out according to the recommendation of Ministry of Agriculture, Egypt.

At 70 days after planting (DAP), a random sample of four plants was taken from each experimental unit to determine the growth parameters of potato plants (plant height and fresh and dry weights/plant. At the harvesting time (120 DAP), the total tuber yields, marketable and unmarketable yield per feddan were recorded. A representative sample of 10 to 15 healthy tubers from each experimental plot was selected from the largest sizes to obtain quality data (dry matter, specific gravity, starch, reducing sugar and nitrate and nitrite content) according to the methods described by (AOAC, 2000).

Nitrogen, phosphorus and potassium accumulation in tubers were estimated based on dry matter and element percentage using the methods described by Cottenie *et al*., (1982).

Data obtained were subjected to statistical analysis by the technique of analysis of variance (ANOVA) according to Snedecor and Cochran (1982). Comparisons among means of treatments were tested using Duncan multiple range test at 5 % level of probability as described by Steel and Torrie (1980).

## RESULTS AND DISCUSSION

### Vegetative growth:

The results of this study indicate that there were significant differences among N-sources and nitrification inhibitor DCD in all vegetative growth characters as shown in Table 2.

Potato plants received polyolefin-coated urea PCU gave more plant height and fresh and dry weights per plant as compared with other treatments, in both seasons. Meanwhile, application of urea + DCD gave the lowest values of vegetative growth parameters.

The best results obtained by using PCU can be attributed to the slow release of nitrogen to meet potato plants requirement, where the coat of urea with polyolefin can low the dissolution rate of urea than AN (soluble form), so reduce N loss from soil, gradually hydrolyzed in parallel with the plant demand, gives a chance for more nitrogen uptake by plant roots and gradual improvement in N-supply power for improving N efficiency of slow release as compared with soluble form (Waddell *et al*., 1999; Zvomuya *et al*., 2003).

### Tuber Yield:

Regarding, the effect of N-sources on total tuber yield and yield components, data presented in Table 3 indicate that the highest increments in values of total tuber, and marketable yields were obtained in case of PCU and IBDU applications. On the other hand, U + DCD gave the lowest values in this respect.

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As regard to unmarketable yield, application of compost led to significant decrease, in this respect.

Generally, all slow N-fertilizers significantly improved total and marketable tuber yield with soluble form (Table 3).

Differences in yield among all N-sources could be due to high and earlier leaching, which resulted in greater $NO_3^-$ loss under furrow irrigation (like our investigation conditions). These results are in accordance with those obtained by Zvomuya *et al*. (2003). Westermann and Kleinkopf (1985) noted that decreased N-uptake resulting from depleted soil $NO_3$-N can reduce tuber bulking rates, size, and yields. Because PCU release N slowly, N loss through leaching is minimized, resulting in higher yields and larger tubers compared with soluble form. It has also been reported that the benefits of CRFs relative to soluble fertilizers in potato production are associated with the continued supply of N during tuber bulking and earlier tuber initiation (Cox and Addiscott, 1976; Pack, 2004).

The present results corroborate earlier findings by Zvomuya and Rosen (2001) and Zvomuya *et al*. (2003). These authors obtained higher yields and larger tubers with a 1:1 blend of 50- and 70-d PCU formulations than three applications of urea during leaching seasons. In a majority of studies, traditional CRFs have resulted in lower potato yields than soluble fertilizers (Lorenz *et al*., 1972; Cox and Addiscott, 1976; Waddell *et al*., 1999). Poor performance of the CRFs in these studies was mostly due to unpredictable release of N, which did not match crop demand.

**Tuber quality:**

Data of Table 4 show that different N-sources had direct effect on tuber quality. Application potato plants with PCU or IBDU significantly increased tuber dry matter, specific gravity and starch and reduced significantly reducing sugars, compared with other treatments, in both seasons.

It could be attributed that the PCU or IBDU fertilizers maintain the nutrients supply to the plants during growth period more than soluble form. These increases in dry matter, starch and specific gravity may be attributed to the effect of slow release fertilizers on increasing the availability of certain elements and their supply to plant (Table 5). These results were confirmed with those of Waddell *et al*. (1999) and Pack (2004).

Tuber specific gravity is one of primary importance since it determines the weight of processed product than can be recovered from a given weight of potato tubers (Kleinkopf *et al*., 1987).

All specific gravity values were greater than 1.0800, indicating high tuber quality suitable for processing and other uses (Table **4**). PCU resulted in significantly higher specific gravity in both seasons. Martin *et al*. (1993) reported a similar effect for the cultivar 'Atlantic'. However, this finding contradicts other studies where reductions in specific gravity were reported at higher rates of applied N (soluble form) (Ojala *et al*., 1990). Westermann and Kleinkopf (1985) demonstrate that treatments, such as higher N rate, that increase tuber yields after reduce specific gravity.

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## Chemical constituents of potato tubers:

Data presented in Table 5 show that, there were significant differences among all soluble and slow release N-fertilizers with DCD in tuber NPK contents, and nitrate as well as nitrite content in potato tuber, in both seasons. The highest values in NPK-uptake were obtained in treatments amended with PCU and IBDU followed by SCU. On the other hand, AN produced higher nitrate and nitrite content in potato tubers. This is true in two seasons of study. Similar results were found by Zvomuya *et al*. (2003).

This may be attributed to the increase in growth characteristics (Table 2) of the plant and linked this to nitrogen accumulation patterns (i.e., little N demand in very early, to heavy N demand during vegetative growth and bulking stages, to little N demand during maturation and senescence (Pack, 2004) which allow to increase P and K concentrations.

Pack (2004) found that all controlled release fertilizers (CRFs) can improve N-use efficiency. In other studies, recoveries of 50 to 60% have been reported for Russet Burbank potatoes fertilized with soluble N fertilizers (Joern and Vitosh, 1995).

Based on the dissolution rate of the PCU and at the recommended rate of 280 kg N ha-1, the $RE_{diff}$ values obtained study translate to recoveries of 80, 64 and 91% of released N for 1997, 1998, and 1999, respectively (Zvomuya *et al*., 2003).

## Economic return per feddan:

The results in Table 6 show that the highest net return (11.903 L.E.) was obtained from PCU treatment in comparison with other treatments. Thus, this treatment proved to be economical for potato production. As a support for the present results, Hutchinson and Simonne (2003) and Ezzat and Abd El-Hameed (2010) indicated that one possibility for lowering the cost of planting would be the use of controlled-release fertilizers.

## Conclusion:

Under the conditions of this study, this investigation suggest that, application of nitrogen fertilizers in the form of polyolefin-coated urea (PCU), or isobutylidene diurea (IBDU) at 135 kg $fed^{-1}$ in potato fields is indispensable to increase the vegetative characteristics, yield parameters and quality of tubers, in addition to lower concentrations in both nitrate and nitrite in tubers than the recommended rate of soluble form.

Moreover, the application of slow release fertilizers will save about 25% of the required amounts of N-fertilizer, and will also reduce the pollution of environment. On the other side, the use of slow release fertilizers will reduce potato production cost especially in the developing countries like Egypt, and give the highest net profit for farmers.

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# تأثير مصادر مختلفة من النتروجين مع مثبطات التأزت علي انتاجية وجودة نباتات البطاطس

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نفذت تجربتان حقليتان فى مزرعة خاصة (كفر علام - مركز منية النصر) بالقرب من مدينة المنصورة - محافظة الدقهلية في الموسمين الشتويين 2009/2008 و 2010/2009 لدراسة **مدي** استجابة نباتات البطاطس (صنف ديامونت) لمصادر مختلفة من الأسمدة النتروجينية، سواء كانت في صورة ذائبة (نترات نشادر، سلفات نشادر و يوريا) بصورة منفردة **أو مع** مثبط التأزت داي سيناميد DCD أو في صورة أسمدة بطيئة الأمداد (يوريا فورم، يوريا مغلفة بالكبريت، ايزوبيوتيل داي يوريا، يوريا مغطاة ببولي أوليفين والكمبوست) وتأثير ذلك علي النمو والمحصول وجودة الدرنات وتراكم النترات والنتريت في الدرنات.

**ويمكن تلخيص أهم النتائج المتحصل عليها كما يلي:**

1 - أثرت الأسمدة بطيئة الإمداد معنويا علي جميع الصفات المدروسة مقارنة بالصور الذائبة من الأسمدة النتروجينية.
2 - تفوقت معنويا المعاملة بأضافة يوريا مغطاة ببولي أوليفين (135 كجم/فدان) في الصفات الخضرية محل الدراسة (ارتفاع النبات، الوزن الطازج، الوزن الجاف للنبات)، وكذلك صفات المحصول (المحصول الكلي، المحصول القابل للتسويق)، بينما أدت نفس المعاملة الي نقص معنوي في الدرنات صغيرة الحجم في كلا الموسمين، يليها المعاملة بأضافة ايزوبيوتيل داي يوريا عند نفس المعدل السابق من النتروجين.
3 - أدي استخدام سماد يوريا مغطاة ببولي أوليفين وسماد ايزوبيوتيل داي يوريا إلي زيادة معنوية في صفات جودة الدرنات (نسبة المادة الجافة للدرنات، الكثافة النوعية ونسبة النشا) وكذلك المحتوي من النيتروجين والفوسفور والبوتاسيوم في الدرنات في كلا الموسمين بالنسبة للمعاملات الأخري.
4 - علي الجانب الأخر.. سجل أعلي محتوي للدرنات من النترات والنتريت في المعاملة السمادية بالصورة الذائبة من نترات النشادر الجيري بمعدل 180 كجم/فدان، في كلا الموسمين مقارنة بباقي المعاملات.

تقترح هذه الدراسة أن استخدام الأسمدة بطيئة الإمداد ( يوريا مغطاة ببولي أوليفين وايزوبيوتيل داي يوريا) بمعدل 135 كجم للفدان هام لأنتاج مثالي في حقول البطاطس وأعطاء أعلي محصول وجودة للدرنات مع خفض تركيز النترات والنيتريت مع أعطاء أعلي صافي ربح للمزارعين مقارنة بالمعدل الموصي به (180 كجم ن) من الصورة الذائبة من سماد نترات النشادر. علي الجانب الأخر فأن استخدام الأسمدة بطيئة الأمداد بمعدل 135 كجم فدان سيوفر 25% من المعدل الموصى به من السماد الأزوتي، وذلك تحت ظروف هذه الدراسة.

**قام بتحكيم البحث**

| | |
|---|---|
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**Table 2: Vegetative growth characters of potato as affected by nitrogen sources and nitrification inhibitors in 2008/09 and 2009/10 seasons.**

| Treatments | Plant height (cm) | | Fresh weight/plant (g) | | Dry weight/plant (g) | |
|---|---|---|---|---|---|---|
| | **2008/09** | **2009/10** | **2008/09** | **2009/10** | **2008/09** | **2009/10** |
| 1. Ammonium nitrate (AN) | 51.00 d | 52.00 ef | 390.89 fg | 438.26 e | 36.17 ef | 36.10 fg |
| 2. Ammonium sulphate (AS) | 50.33 d | 51.00 fg | 380.39 g | 410.16 f | 34.00 fg | 38.12 ef |
| 3. Urea (U) | 52.00 cd | 52.67 ef | 400.76 f | 446.12 de | 38.40 de | 38.16 ef |
| 4. Compost | 54.00 b | 56.33 bc | 462.36 d | 486.23 c | 42.62 b | 42.18 c |
| 5. AN + DCD* | 48.33 e | 49.67 g | 360.28 h | 390.67 g | 34.14 fg | 34.72 g |
| 6. AS + DCD* | 55.00 b | 57.00 bc | 480.18 c | 508.20 b | 42.56 b | 44.56 b |
| 7. U + DCD* | 46.67 e | 47.33 h | 338.52 i | 381.70 g | 32.20 g | 32.11 h |
| 8. Ureaform (UF) | 52.00 cd | 53.33 de | 427.11 e | 460.65 d | 39.35 cd | 40.05 de |
| 9. Sulpher coated urea (SCU) | 53.33 bc | 55.00 cd | 448.20 d | 482.10 c | 41.04 bc | 41.67 cd |
| 10. Isobutylidene diurea (IBDU) | 57.67 a | 58.33 ab | 510.62 b | 530.89 a | 43.23 ab | 46.08 ab |
| 11. Polyolefin-coated urea (PCU) | 58.33 a | 60.00 a | 540.30 a | 542.37 a | 45.26 a | 47.12 a |

**Means followed by the same letter (s) within each column do not significantly differ using Duncan's Multiple Range Test at the level of 5%.**
***DCD: dicyandiamide; nitrification inhibitors.**

**Table 3: Tuber yield characters of potato as affected by nitrogen sources and nitrification inhibitors in 2008/09 and 2009/10 seasons.**

| Treatments | Total tuber yield (ton fed$^{-1}$) | | Marketable tuber yield (ton fed$^{-1}$) | | Unmarketable tuber yield (ton fed$^{-1}$) | |
|---|---|---|---|---|---|---|
| | **2008/09** | **2009/10** | **2008/09** | **2009/10** | **2008/09** | **2009/10** |
| 1. Ammonium nitrate (AN) | 10.650 ef | 10.750 ef | 9.997 d | 10.075 e | 0.653 c | 0.668 c |
| 2. Ammonium sulphate (AS) | 10.200 fg | 10.300 fg | 9.518 e | 9.612 ef | 0.682 bc | 0.688 c |
| 3. Urea (U) | 10.860 de | 10.920 de | 10.095 d | 10.108 e | 0.765 a | 0.812 a |
| 4. Compost | 11.860 b | 11.800 b | 11.505 b | 11.500 bcd | 0.355 h | 0.300 h |
| 5. AN + DCD* | 9.730 gh | 9.860 gh | 9.254 e | 9.400 f | 0.476 e | 0.460 e |
| 6. AS + DCD* | 12.010 b | 12.130 ab | 11.557 b | 11.710 abc | 0.450 ef | 0.420 f |
| 7. U + DCD* | 9.400 h | 9.560 h | 8.687 f | 8.807 g | 0.711 b | 0.753 b |
| 8. Ureaform (UF) | 11.180 cd | 11.260 cd | 16.660 c | 10.993 d | 0.520 d | 0.600 d |
| 9. Sulpher coated urea (SCU) | 11.630 bc | 11.700 bc | 11.177 b | 11.240 cd | 0.453 ef | 0.460 e |
| 10. Isobutylidene diurea (IBDU) | 12.540 a | 12.300 a | 12.132 a | 11.958 ab | 0.408 g | 0.342 g |
| 11. Polyolefin-coated urea (PCU) | 12.850 a | 12.530 a | 12.430 a | 12.142 a | 0.420 fg | 0.388 f |

**Means followed by the same letter (s) within each column do not significantly differ using Duncan's Multiple Range Test at the level of 5%.**
***DCD: dicyandiamide; nitrification inhibitors.**

**Table 4: Tuber quality of potato as affected by nitrogen sources and nitrification inhibitors in 2008/09 and 2009/10 seasons.**

| **Treatments** | **Tuber dry matter (%)** | | **Specific gravity of tubers** | | **Starch (%)** | | **Reducing sugars (%)** | |
|---|---|---|---|---|---|---|---|---|
| | **2008/09** | **2009/10** | **2008/09** | **2009/10** | **2008/09** | **2009/10** | **2008/09** | **2009/10** |
| 1. Ammonium nitrate (AN) | 21.82 ef | 21.30 d | 1.0800 cd | 1.0785 cd | 14.14 ef | 14.46 cde | 0.260 ab | 0.273 ab |
| 2. Ammonium sulphate (AS) | 22.10 d | 22.00 c | 1.0832 cd | 1.0860 a-d | 14.20 ef | 14.30 de | 0.253 abc | 0.268 ab |
| 3. Urea (U) | 21.00 h | 20.60 e | 1.0782 cd | 1.0758 d | 13.37 h | 13.62 f | 0.292 a | 0.289 a |
| 4. Compost | 22.30 c | 22.36 b | 1.0856 bcd | 1.0873 abc | 14.96 bc | 15.06 bc | 0.189 def | 0.196 cd |
| 5. AN + DCD* | 22.00 de | 22.10 c | 1.0860 bc | 1.0852 a-d | 13.90 fg | 14.12 def | 0.243 a-d | 0.258 ab |
| 6. AS + DCD* | 22.12 cd | 21.18 d | 1.0876 bc | 1.0822 bcd | 14.48 de | 14.52 cde | 0.218 b-e | 0.220 bc |
| 7. U + DCD* | 21.30 g | 20.65 e | 1.0761 d | 1.0763 d | 13.62 gh | 14.00 ef | 0.286 a | 0.280 a |
| 8. Ureaform (UF) | 21.67 f | 21.28 d | 1.0811 cd | 1.0793 cd | 14.63 cd | 14.70 bcd | 0.271 ab | 0.286 a |
| 9. Sulpher coated urea (SCU) | 22.52 b | 22.42 b | 1.0920 ab | 1.0911 ab | 15.23 b | 15.34 ab | 0.200 c-f | 0.188 cd |
| 10. Isobutylidene diurea (IBDU) | 22.86 a | 22.75 a | 1.0980 a | 1.0941 a | 15.89 a | 15.78 a | 0.176 ef | 0.163 d |
| 11. Polyolefin-coated urea (PCU) | 22.70 ab | 22.66 a | 1.0995 a | 1.0930 a | 15.70 a | 15.80 a | 0.151 f | 0.148 d |

**Means followed by the same letter (s) within each column do not significantly differ using Duncan's Multiple Range Test at the level of 5%.**

***DCD: dicyandiamide; nitrification inhibitors.**

**Table 5: Chemical constituents in potato tubers as affected by nitrogen sources and nitrification inhibitors in 2008/09 and 2009/10 seasons.**

| Treatments | N-uptake (mg/100 D. W.) | | P-uptake (mg/100 D. W.) | | K-uptake (mg/100 D. W.) | | $NO_3^-$ content (mg/ kg F. W.) | | $NO_2^-$ content (mg/ kg F. W.) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2008/09 | 2009/10 | 2008/09 | 2009/10 | 2008/09 | 2009/10 | 2008/09 | 2009/10 | 2008/09 | 2009/10 |
| 1. Ammonium nitrate (AN) | 708.03 efg | 738.22 cd | 73.66 def | 72.95 efg | 841.66 cd | 1076.11 bcd | 66.18 a | 68.66 a | 0.64 a | 0.67 a |
| 2. Ammonium sulphate (AS) | 740.23 def | 700.31 de | 75.28 def | 76.81 d-g | 826.73 cd | 986.78 cde | 58.10 ab | 60.28 ab | 0.55 ab | 0.58 ab |
| 3. Urea (U) | 618.15 g | 592.38 f | 62.82 g | 60.61 h | 730.26 d | 870.62 e | 62.32 a | 62.72 ab | 0.58 ab | 0.54 bc |
| 4. Compost | 863.78 abc | 808.02 bc | 82.18 bcd | 84.28 bcd | 1083.11 ab | 1180.80 abc | 27.88 fg | 26.13 f | 0.28 fg | 0.31 efg |
| 5. AN + DCD* | 680.10 fg | 636.16 ef | 70.10 efg | 72.12 efg | 788.28 d | 963.70 de | 50.74 bc | 53.10 bc | 0.51 bc | 0.50 bc |
| 6. AS + DCD* | 780.33 cde | 735.28 cd | 78.33 cde | 78.00 c-f | 862.16 cd | 1176.40 abc | 46.78 cd | 48.33 cd | 0.40 cde | 0.43 cde |
| 7. U + DCD* | 662.28 fg | 612.82 ef | 67.67 fg | 68.12 gh | 770.73 d | 918.20 de | 48.11 cd | 52.17 bc | 0.48 bcd | 0.46 bcd |
| 8. Ureaform (UF) | 810.31 bcd | 780.11 bcd | 80.21 cd | 81.30 cde | 880.22 cd | 1108.13 bcd | 40.50 de | 40.08 de | 0.42 cde | 0.42 cde |
| 9. Sulpher coated urea (SCU) | 875.10 abc | 826.78 bc | 85.16 bc | 86.53 abc | 990.10 bc | 1200.52 ab | 38.18 e | 36.11 ef | 0.38 def | 0.34 d-g |
| 10. Isobutylidene diurea (IBDU) | 940.16 a | 922.10 a | 94.18 a | 93.20 a | 1218.32 a | 1252.12 ab | 22.20 g | 26.22 f | 0.26 g | 0.28 g |
| 11.Polyolefin-coated urea (PCU) | 898.26 ab | 850.70 ab | 90.13 ab | 91.42 ab | 1165.13 a | 1342.16 a | 32.34 ef | 36.20 ef | 0.32 efg | 0.30 fg |

**Means followed by the same letter (s) within each column do not significantly differ using Duncan's Multiple Range Test at the level of 5%.**
***DCD: dicyandiamide; nitrification inhibitors.**

**Table 6: Estimate of additional net return of treatments.**

| **Treatments** | **Tuber yield* (Ton fed$^{-1}$)** | **Gross return (£.Є fed$^{-1}$)** | **Treatment cost** (£.Є fed$^{-1}$)** | **Total costs*** (£.Є fed$^{-1}$)** | **Net return (£.Є fed$^{-1}$)** | **Benefit / cost ratio****** | **Order** |
|---|---|---|---|---|---|---|---|
| 1. Ammonium nitrate (AN) | 10.70 | 16,050 | 859.70 | 5859.70 | 10,190 | 1.7 | 8 |
| 2. Ammonium sulphate (AS) | 10.25 | 15,375 | 1317.00 | 6317.00 | 9,058 | 1.4 | 9 |
| 3. Urea (U) | 10.89 | 16,335 | 352.20 | 5352.20 | 10,983 | 2.1 | 5 |
| 4. Compost | 11.83 | 17,745 | 900.00 | 5900.00 | 11,845 | 2.0 | 2 |
| 5. AN + DCD* | 9.80 | 14,700 | 869.70 | 5869.70 | 8,830 | 1.5 | 11 |
| 6. AS + DCD* | 12.07 | 18,105 | 1327.00 | 6327.00 | 11,778 | 1.9 | 3 |
| 7. U + DCD* | 9.48 | 14,220 | 362.20 | 5362.20 | 8,858 | 1.7 | 10 |
| 8. Ureaform (UF) | 11.22 | 16,830 | 1491.71 | 6491.71 | 10,338 | 1.6 | 7 |
| 9. Sulpher coated urea (SCU) | 11.67 | 17,505 | 1687.50 | 6687.50 | 10,818 | 1.6 | 6 |
| 10. Isobutylidene diurea (IBDU) | 12.42 | 18,630 | 2531.22 | 7531.22 | 11,099 | 1.5 | 4 |
| 11.Polyolefin-coated urea (PCU) | 12.69 | 19,035 | 2131.58 | 7131.58 | 11,903 | 1.7 | 1 |

***Tuber yield as average of two seasons.**

****Treatment cost was calculated according to the following prices: Price of compost £.Є 50/ton; ammonium nitrate £.Є 1.60/kg; ammonium sulphate £.Є 1.50/kg; urea £.Є 0.90/kg; UF £.Є 4.00/kg, SCU £.Є 4.00/kg, IBDU £.Є 6.00/kg, PCU £.Є 6.00/kg, and finally, price of produce, £.Є 1500/ton**

*****Total costs include leasehold, labor, PK fertilizers, pesticides, microelements and other cultural practices which equal nearly £.Є 5000, plus treatment cost.**

******Benefit/cost ratio was divided by net return in total costs**