Improving maize (*Zea mays* L.) performance in semi-arid Zimbabwe through micro-dosing with ammonium nitrate tablets

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Abstract

Although the application of small quantities of nitrogen fertiliser has improved cereal yields on low-input farms in semi-arid Zimbabwe, the practice is reported to be laborious and time-consuming by farmers. In an effort to make micro-dosing less labour-intensive and more precise, an ammonium nitrate (AN) tablet the equivalent of a micro-dose of prill AN (28 kg N ha^{-1}) applied per maize plant was developed by ICRISAT in collaboration with Agri-seeds, Zimbabwe. This study characterized the physical stability, chemical (N% and solubility) and agronomic performance of AN tablets compared to prill. Only 10% of tablets broke when dropped from 2 m showing that they are physically stable and can handle rough treatment The N content in the tablets (33.3 %) was comparable to that in prill AN (34.6%). However, the tablet formulation took twice as long to dissolve than prill AN when placed on a wet soil. Despite this difference in solubility, simple leaching column experiments suggest that less than 2% of the total AN applied was lost due to leaching. Agronomic trials were super-imposed on the paired-plot demonstrations used to promote micro-dosing and the conservation agriculture

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tillage technique of planting basins from 2005 to 2008. Each tillage (plough and basins) plot was sub-divided into three sub-plots on which the no AN, prill AN and tableted AN treatments were super-imposed. Maize was planted and management of plots was left to the farmer. Micro-dosing with either prill or tableted AN significantly ($P < 0.001$) increased maize grain yield by over 40% in all seasons for planting basins. However, on the ploughed plot there was no yield benefit to using either AN formulation in the season with the lowest rainfall (2006/07). There was no significant difference in grain yield and agronomic nitrogen use efficiency between prill and tableted AN formulations except for 2005/06 season in the planting basins. In this season in planting basins, tableted AN had significantly ($P < 0.001$) higher rainwater productivity than prill AN which translated into greater grain yield. In addition, the most benefit to micro-dosing was observed to accrue when combined with water harvesting techniques such as planting basins. An observation supported by the host farmers, who in the second and third seasons chose to apply available basal soil fertility amendments to the basin plots over the flat plots. Thus, AN tablets if available at an affordable price can be used by smallholder farmers to more precisely apply N fertiliser. Future work should focus on the labour issues of micro-dosing and making cost-effective tablets available to resource-poor farmer, and also addressing other limiting soil nutrients.

Keywords: Micro-dosing, ammonium nitrate, tablet, tillage, *Zea mays* L., productivity

INTRODUCTION

Cereal yields in the rainfed semi-arid tropical agroecosystems of sub-Saharan Africa are low, typically less than 1 tha^{-1}, mainly due to poor crop management rather than low physical potential (SIWI, 2001). Among the sub-optimal farmer practices in the region is nutrient management (Giller *et al.,* 2006). Fertiliser use in sub-Saharan African agriculture is the least in the world (Rockström, 2000) with many countries in southern Africa using less than 8.5 kg ha^{-1} (Twomlow *et al*., 2006a). Surveys carried out by Rusike *et al.* (2003) in semi-arid southern Zimbabwe indicated that less than 5 % of farmers commonly used fertilisers at the recommended rates. The main reason cited by farmers for low use of fertiliser in semi-arid areas is the high risk of crop failure as a result of droughts and dry spells. As fertiliser is the most costly cash input used by tropical smallholder farmers in southern Africa (Twomlow *et al.,* 2006b), with fertilisers in Africa costing six times as much as those in Europe, North America or Asia (Sanchez, 2002), most farmers in dry areas are unable to invest in fertiliser.

The result of the low use of fertiliser is depletion of soil fertility that along with the concomitant problems of weeds, pests and diseases is believed to be the major biophysical cause of low per capita food production in Africa (Sanchez, 2002). To reverse the trend of nutrient depletion, there is a need to develop fertiliser use technologies tailored to smallholders' climatic and socio-economic conditions. One such strategy is the micro-dosing technology that is being promoted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in low potential areas of the Sahel (Tabo et al., 2007) and southern Africa (Twomlow *et al*., 2010). According to Carberry *et al.* (2004) farmers in environments of low and erratic rainfall are better off applying lower rates of nitrogen fertiliser on more fields, than concentrating a limited supply on one field at the current fertiliser recommendation rates. The micro-dosing rate currently promoted in semi-arid Zimbabwe is 17 kg N ha^{-1}, which is about 34% of the recommended rate of 50 kg N ha^{-1} for these areas. Results from a scaling out program of micro-dosing on farmers' fields in Zimbabwe showed that smallholder farmers increased their yields from a little as 750 kg ha^{-1} to more than 1400 kg ha^{-1} by applying as little as 10 kg of N ha^{-1} (Twomlow *et al*., 2010). Thus, micro-dosing may be a useful strategy to familiarize farmers with nitrogen fertiliser use and increase cereal production.

Although application of N fertilisers often leads to crop yield increases, results from studies under smallholder conditions show that fertiliser use efficiency is quite low. Mushayi *et al*. (1998) reports that on farmer-managed fields 3.6 kg maize (Z*ea mays* L.) grain kg^{-1} of applied N was produced compared to 12.4 kg grain kg^{-1} applied N on researcher-managed plots. The low agronomic nitrogen use efficiency (ANUE) on smallholder farms can be attributed to poor management of N resources due to lack of information on fertiliser use and sub-optimal crop management practices. Poor timing of field operations, management of pests and diseases as well as other nutrient deficiencies contribute to low ANUE on farmer's fields (Mushayi *et al*., 1998). Furthermore, soils in the smallholder farming sector of Zimbabwe are predominantly sandy, and a number of studies suggest that leaching of N fertilisers is a serious risk, especially when applied at the recommended rates (Chikowo *et al*., 2003; Nyamangara *et al.,* 2003; Nyamangara, 2007).

Thus, the micro-dosing recommendation of spot application of N fertiliser to a well-managed cereal plant between 4 to 6 weeks after crop emergence does make N fertiliser application more economic for the farmers (Twomlow *et al*., 2010) and is likely to improve ANUE. In environments where water is limiting, improved management practices such as fertiliser application and conservation tillage often result in "more crop per drop of rainwater" leading to high rainwater productivity and crop yields (Rockström *et al*., 2003). According to Steiner & Rockström, (2003) and Rockström et al. (2008) maximum crop yields in drought prone areas can only be obtained by combining soil fertility management with water harvesting techniques. Conservation tillage practices (e.g. Planting Basin) that include precision application of both basal and top dress fertilisers are currently being promoted in smallholder agriculture by a number of development and agriculture research organizations in Zimbabwe (Twomlow *et al*., 2009).

However, since the majority of smallholder households are labour-constrained (Steiner & Twomlow, 2003), the benefits of micro-dosing are unlikely to be realized to a large extent. This is because the current micro-dosing practice has been reported by practitioners to be very time consuming and laborious (ICRISAT unpublished Field Visit Reports). Farmers in Zimbabwe are currently using the commonly available Crowne bottle caps to apply nitrogen fertiliser microdose, at a rate of one crowne bottle cap shared between three maize plants. This equates to 12 400 caps ha^{-1} for a maize crop planted at a spacing of 30 x 90 cm (Twomlow *et al.,* 2010). However, labour bottlenecks develop at the recommended time of N application as farmers have other tasks such as planting of late crops and weeding early planted crops (Makanganise *et al*., 2001). Consequently weeding and / or N fertiliser application is delayed leading to decreased crop productivity. One solution devised for this problem by ICRISAT in collaboration with Agri-Seeds Service, Zimbabwe was to formulate a nitrogen fertiliser tablet that was the equivalent of prill AN contained in one third of a Crowne bottle cap. In the production process, a pharmaceutical binding agent was used to improve the handling characteristics of the tablet. The perceived advantage of using a tablet over the bottle cap is that less time is spent dividing cap into three portions, it is easier to spot place and could eventually be mechanized. However, for these N tablets to be useful to farmers, they should be at least as productive as the prill N fertiliser, easy to handle and resistant to damage during transportation.

The objectives of this study were to determine some of the physical and chemical properties of the tableted N compared to the prill formulation; and to quantify agronomic response of maize grown under two tillage practices (conventional and basins) in farmer-managed trials to micro-dosing with the two AN formulations. No attempt was made to assess the labour issues associated with microdosing, as access to the farmers during the cropping season was restricted due to political disturbances.

MATERIALS AND METHOD

Physical and chemical properties of ammonium nirate tablets

Physical stability

To mimic transport from the factory, to the retailer and finally to the farmer a simple integrity test of the tablets was carried out. Bags containing 50 tablets were dropped 10 times from heights of 1 and 2 m, and the numbers of broken tablets were then counted.

Percentage N

Since tablets use a binding agent, it was expected that the total N content would be lower than the equivalent weight of pure prilled AN. Therefore, both AN forms were also analysed (*n*=5) for total N content using distillation and titration (Kjeldahl method) (AOAC, 1990).

Solubility

Since the tablets use a pharmaceutical binding agent, it was hypothesized that the rate at which the AN will dissolve could be different from the prilled form. This dissolution time could affect the release of N from the tablets to the root zone of the crop, and even reduce potential leaching. In the laboratory, solubility of the two formulations of AN fertiliser was tested in distilled water. The test in distilled water used Erlenmeyer flasks filled with 50 ml of water. An equal amount (mass) of each AN type was left in the flask and the time taken to dissolve recorded (*n*=5). In the field, prilled and tablet form of AN were either surface applied (*n*=5) or incorporated into soil to a depth of about 1 cm (N=5). Soil was either slightly moist (dry soil) from previous rains or thoroughly wetted to simulate a significant rain shower (20 mm equivalent) (wet soil). The time that it took for complete dissolution of the tablets and the prill was determined visually and recorded.

Simple Leaching Tests

To see if the tablet formulation had the potential to reduce the quantity of N leached compared to prill a series of simple laboratory based leaching tests were undertaken for a range of antecedent soil condition in response to different rainfall events. For these tests a nutrient poor coarse grained sandy soil from ICRISATs Lucydale site in southern Zimbabwe (see Ncube *et al.,* (2007) for a description of this soil) was air dried and sieved through a 2 mm sieve, prior to being packed into plastic columns (0.2 m diameter by 0.2 m height) to a bulk density of 1.5 t m^{-3}. Muslin cloth was stretched across the base of each column, and the column was then placed on 0.2 m diameter filter funnel packed with glass wool. A beaker was placed at the base of the filter funnel to collect drainage water.

At the start of each experimental run the columns were wetted up from the base until free water appeared on the soil surface, and then allowed to drain freely. Once drainage water had ceased flowing from the base of the column the fertiliser treatments were applied. The treatments were fertilization (Zero Fertilization – control; 1.4 g prilled fertiliser; a single fertiliser tablet) by size of simulated rainfall event (10 mm, 20 mm,30 mm, 40 mm, 50 mm) by antecedent soil conditions (number of days simulated rainfall occurred after application of fertiliser -(0, 1, 2, 4 and 8 days). The simulated rainfall event sizes and days between events were determined from rainfall analyses undertaken for Matopos research Station by Mupangwa (2009). Each treatment combinations was replicated 3 times (n=3).

Once an experimental event commenced the total volume of leachate was recorded for each column and its NO_3–N was determined using the colorimetric method of Anderson & Ingram (1993) and the total mg of NO_3–N calculated for each treatment combination. Once all of the treatment combinations had been completed the background NO_3–N leached from the control columns was subtracted from the quantities of NO_3–N leached from the fertilized columns an analyses of variance was undertaken.

Agronomic trials

Study site

On-farm trials were conducted in Masvingo (19^{0}64$^{'}$S, 310 49$^{'}$E) and Chivi (19^{0}93$^{'}$S, 310 09$^{'}$E) districts of Masvingo Province, Zimbabwe. Zimbabwe is divided into five agro ecological regions, also known as Natural Regions I–V. Natural Regions I and II receive the highest rainfall (at least 750 mm per annum) and are suitable for intensive farming. Natural Region III receives moderate rainfall (650–800 mm per annum) and
Natural Regions IV and V have fairly low annual rainfall (450–650 mm per annum) and are suitable for extensive farming (adapted from Vincent & Thomas, 1960).

The communal areas of Masvingo district are mainly under Natural Region IV although the area around Great Zimbabwe and Lake Mutirikwi receives heavy but irregular rainfall and comprises the 7% of the district that is classified as Natural region III (Balarin, 1982). Trials in this study were sited in both Natural Regions III and IV. The rainfall season in Masvingo province is unimodal starting from October and ending in March (Hagmann, 1995). The 45-year (1953-1998) average for Masvingo district is 582 mm with a range of 143 to 1037 (Mugabe *et al*., 2004). Chivi, classified as Natural Region V, is one of the driest districts in Masvingo Province. The crop growing season is characterized by low and highly inconsistent rainfall with an average rainfall of 544 mm for the period 1914 to1988 with a range of 143 to 1123 mm (Mugabe *et al.,* 2004). Soils in both Masvingo and Chivi districts are a fersiallitic types (Nyamapfene, 1991), predominantly sandy loam in Masvingo and sandy in Chivi district. The soils are of inherently low soil fertility (Table 1). Despite the low rainfall and marginal soils, the smallholder farmers in the districts practice rainfed crop production. The major crops grown are maize, sorghum, (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R.Br.) and groundnut (*Arachis hypogaea* L.) mainly for home consumption (Mugabe *et al*., 2003). Very similar to smallholder cropping practices described by Ncube *et al.,* (2009) in Tsholotsho District some 200 km to the west.

Table 1. Summary of soil analysis results for the top 0.15 m from Nitrogen tablet micro-dosing trial plots collected from Chivi and Masvingo Districts, Masvingo Province, Zimbabwe in 2006.

Characteristic	Chivi (n = 15)	Masvingo (n = 21)
Mean soil pH	4.6	4.9
Minimum pH	3.8	3.6
Maximum pH	5.6	6.2
Mean total soil N (%)	0.043	0.046
Minimum total N (%)	0*	0.015
Maximum total N (%)	0.083	0.078
Mean total soil P (%)	0.011	0.013
Minimum total soil P (%)	0.002	0*
Maximum total soil P (%)	0.025	0.03

- Outside detection limit of the spectrophotometer available

Farmer Selection and Experimental layout

In each district a meeting was held with the various farmer groups participating in the Protracted Relief Programme with the Non-Government Organizations CARE and The Zishivane Water Project. At each meeting the objectives of the experiment were explained to farmers and volunteers were asked for. Given logistical limitations and availability of tablets, the number of farmers in each district who could host a trial was limited to twenty. Consequently, at each meeting, once a list of volunteers had been obtained a random sub-sample of 20 was then selected with the help of the communities.

The trials were superimposed on the paired plot design used to promote micro-dosing and conservation agriculture (CA) under the Protracted Relief Program in Zimbabwe (Twomlow *et* al., 2006b). Each farmer had two main tillage (conventional farmer tillage and planting basin) plots whose sizes were between 10 by 50 m and 20 by 50 m located adjacent to each other on the same field. Each main tillage plot was divided into three equal sub-plots for N fertiliser application. One of the sub-plots in each tillage plot received no AN fertiliser and will be served as the control plot. The remaining sub-plots received either the prilled or tableted AN formulations. To avoid confusion by the host farmers the AN Fertiliser top dressing rates recommended by the Zimbabwean Conservation Task Force (Twomlow *et al.,* 2008) for the planting basins was also used on the conventionally tilled plots, 28 kg N ha^{-1} rather than the microdosing rate of 17 kg N ha^{-1} that is promoted (Twomlow *et al.,*2010).

In the conventional farmer tillage practice an ox-drawn mouldboard plough was used to till land at what the host farmers considered effective rainfall. The management of basal fertiliser (manure and Compound D) was decided on by the individual farmer, as no basal fertilizer was distributed under the relief programs. Where manure was applied, it was collected from cattle kraal and heaped in field during the dry season (from August). The manure was spread across field and incorporated at ploughing. Compound D (7:14:7 NPK) was applied at planting as per agricultural extension (AGRITEX) recommendations if applied. Maize (SC 403) seed was dribbled behind the plough in every third furrow and covered with the next pass of the plough. Inter-row distance was approximately 90 cm with planting stations 30 cm apart. Timing of Ammonium nitrate (34.5%N) application was determined by the farmer, but was typically between 4 and 6 weeks after crop emergence . Farmers spot applied half a Crowne bottle cap of prill AN per plant to give an application rate of 28 kg N ha^{-1}. For the AN tablet formulation, one and half tablets were applied per maize plant to give an application rate that was equivalent to that applied in prill AN. Farmers placed one tablet per maize plant with another tablet placed halfway between two plants in same row. Weeding was as per farmer practice. Crop was harvested at physiological maturity and grain dried to 12.5% moisture content. This plot will hereafter be referred to as the flat tillage plot.

Management of the adjacent plot with planting basins followed recommendations of the Zimbabwe Conservation Agriculture Taskforce (Twomlow *et al.,* 2008). Land preparation was done in the dry-season after removal of any weeds from field. Hoes were used to dig a permanent grid of planting basins at a spacing of 90 x 60 cm having basin dimensions of 15 x 15 x 15 cm. Cattle kraal manure was applied after basin preparation at a rate of a handful of manure per basin. A typical adult handful of manure weighs about 0.09 kg, thus, approximately 2 ton of manure was spot applied into planting basins. If the host farmer had Compound D available they were free to apply it at a capful per basin in the dry season and covered with a layer of soil. Three maize seeds were planted per basin and thinned to two plants at two weeks after crop emergence to achieve population of 37 037 plants ha^{-1} . Planting took place after the basins had been filled with rainwater and subsequently drained. Farmers applied AN fertiliser at between 4 and 6 WACE. On one sub-plot a Crowne Agent bottle cap of prill AN was applied to each planting basin. On the second plot each planting basin received three AN tablets, whilst one sub plot received no AN fertilizer. Weed and field management was decided by farmers. Under the CA guideline for Zimbabwe (Twomlow *et al.,* 2008), fields are supposed to be kept weed-free. Crop was harvested at physiological maturity and grain dried to 12.5% moisture content. This plot will hereafter be referred to as the basin tillage plot.

Data analysis

Each farmer received a standard catch rainfall gauge and record book in which daily rainfall and all operations undertaken on each plot were recorded. Harvesting was carried out in each gross sub-plot that varied between 160 to 320 m^2 depending on the size of the field that the farmers had chosen to establish the trial. After shelling, maize grain yield per sub-plot was measured and recorded. In 2006 at harvesting, six soil samples were collected from the inter-row area of each tillage main plot using an auger to a depth of 0.15 m. Since the plots were side by side, the samples from each tillage plot were mixed to form one composite sample which was analysed for pH, total nitrogen and phosphorus.

As there were differences in basal fertilization management between the flat and basin tillage practices, the data from the tillage plots was analysed separately and no direct comparisons of the flat and basin tillage were performed.

Agronomic nitrogen use efficiency (ANUE) and rainwater productivity (WP_{rain}) were calculated as follows:

ANUE = (Grain yield with applied nutrients (kg ha^{-1})) – Grain yield for control (kg ha^{-1})) / N applied (kg ha^{-1})

WP_{rain} ((kg ha^{-1} mm^{-1})= Grain yield (kg ha^{-1}) / Seasonal rainfall (mm)

The data were analysed using GenStat Release 9.1 (Lawes Agricultural Trust, 2007) and a General ANOVA model was used to generate treatment means. The treatment and interaction s.e.d were used to separate treatment means at the 5% level of significance.

RESULTS AND DISCUSSION

Physical and chemical properties of AN tablets versus prill

Drop tests showed a tablet breakage of 3.6 % when dropped from a height of 1 m and 7% when dropped from 2 metres. This suggests that the tablet formulation can maintain its integrity even under fairly rough handling. This is important for communal farmers, as fertilisers are not often available in local retail shops and farmers have to travel to nearest towns by buses and open trucks to purchase fertiliser. The tableted AN formulation has about 1.3% less N than the prill form (Table 2) by weight, due to the pharmaceutical binding agent . So, in effect both AN formulations contain about 17 kg of N per 50 kg of AN. However, preliminary tests showed that the solubility of the tableted AN differs from that of prill AN when placed in water and on or within the soil (Table 2 and Fig. 1). Prill AN dissolves 4 times faster than the tableted AN when placed in water and the same trend is observed when prill AN is either placed on or incorporated in the soil. Incorporation of fertiliser in soil and application on moist soil increases the rate of dissolution of both prill and tablet (Fig. 1).

Table 2. Mean nitrogen percentage and dissolution time in distilled water of prill and tablet ammonium nitrate formulations used in the study (N=5)

Ammonium Nitrate formulations	*% N*	*N amount, kg per 50kg bag*	*Dissolution time in distilled water –no shaking, minutes*
Prill	34.6 ± 0.20	17.3	4
Tablet	33.3 ± 0.35	16.6	16

These differences in dissolution rate influenced leaching patterns observed for the two fertiliser formulations as is shown in Figure 2, with total rainfall amounts and antecedent soil conditions having a major influence the amount of NO_3–N leached from the different treatments. When antecedent soil conditions were wet (Fig. 2 – Rainfall 0 days and 1 day after fertiliser application) the two fertiliser formulations behaved in a similar manner until the 50 mm simulated rainfall event when significantly (P=0.042) more N-NO_3 was leached from the soil columns treated with the prilled fertiliser. For 0 days after application of fertiliser 10.3 mg of N-NO_3 was leached from the prilled AN columns compared to only 2 mg from the tableted AN columns – a 5 fold difference. For 1 day after planting 18.8 mg of N-NO_3 was leached from the prilled AN columns compared to only 9 mg from the tableted AN columns – a 2 fold difference. These results do suggest that as the size of storm increases within the first 24 hours of fertiliser application the reduced solubility of the tableted AN (Table 2, Fig. 1) does reduce the rate of leaching

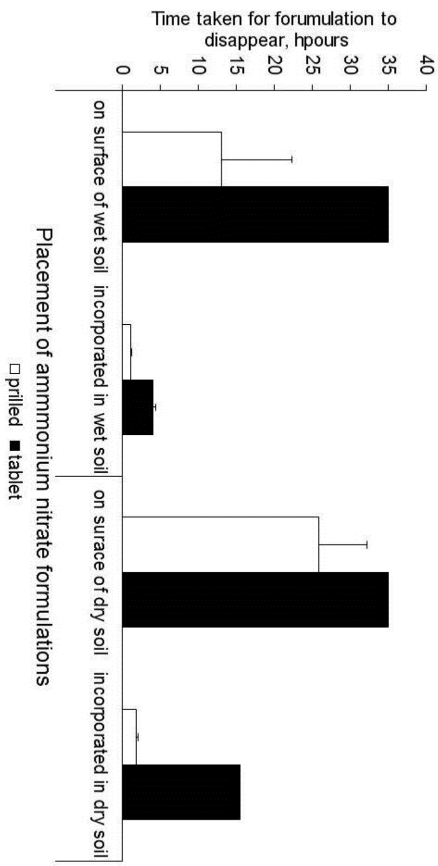

Figure 1. The effect of soil moisture and placement of fertiliser on the average time taken for AN tablet versus the prill formulation to visible disappear under different field conditions. (N=5) Bars represent standard error.

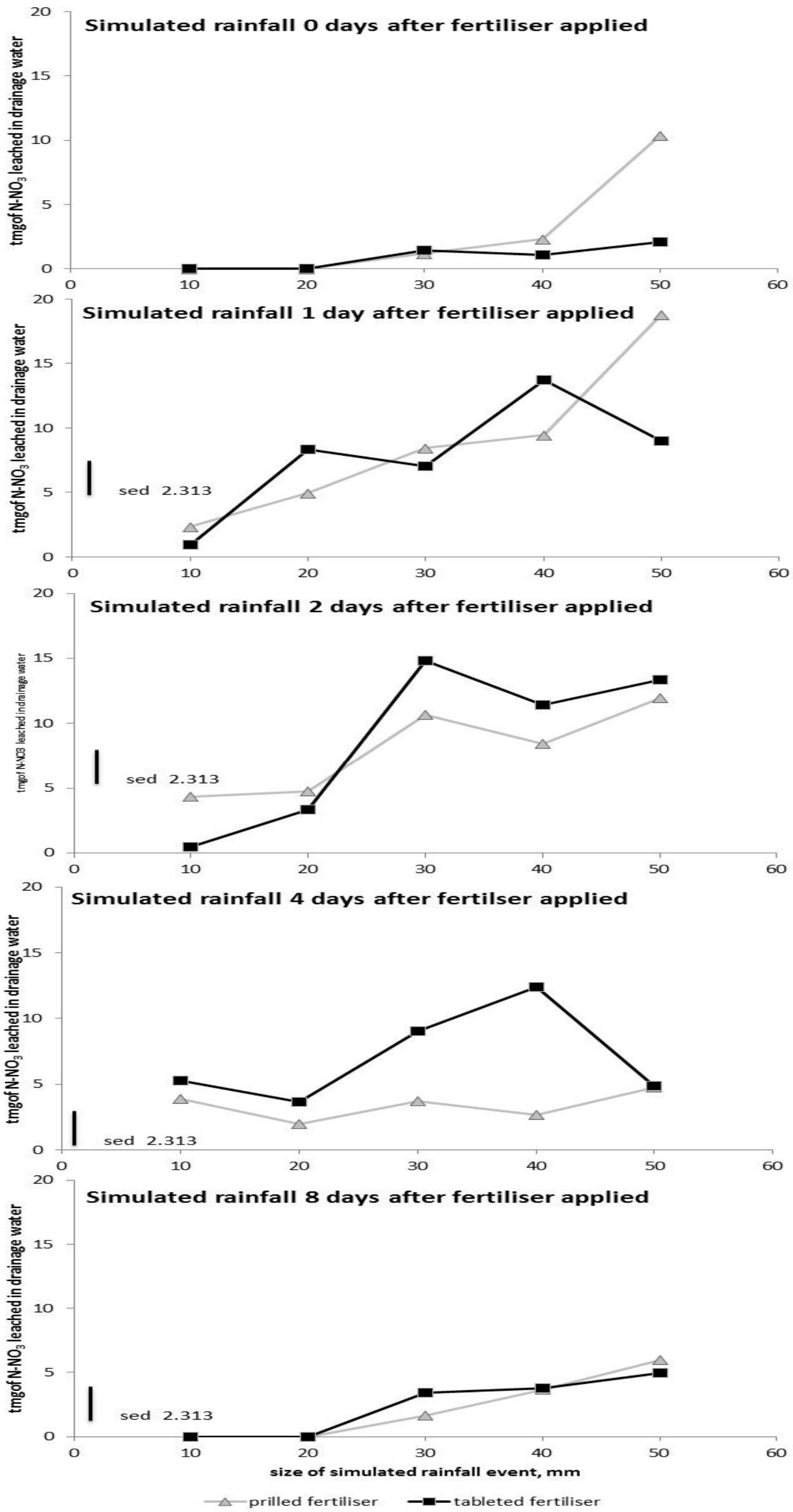

Figure 2. Average Quantities of N-NO_3 (mg) leached from columns (0.2 by 0.2 m) of sandy soil treated with either Prilled AN or Tableted AN following five different simulated rainfall events (10, 20, 30, 40 and 50 mm) occurring 0, 1, 2, 4 and 8 days after the application of the fertiliser (N=3). (P=0.042 for the 3 way interaction with a s.e.d of 2.313).

considerable. In real terms though, the 18.8 mg of $N\text{-}NO_3$ leached following a 50 mm simulated rainfall event from the prilled AN columns (Fig. 2, Rainfall 1 day after application of fertiliser) is less than 2% of the total quantity of prilled AN applied and may be considered negligible. It was only when rainfall was applied 4 days after the fertiliser was added to the columns (Fig. 2, Rainfall 4 days after application of fertiliser) that more $N\text{-}NO_3$ was lost from the tableted AN columns, but not significantly so. This may be due to the fact that the prilled AN had dissolved into the soil and had been absorbed into the soil matrix. By the time 8 days had elapsed (Fig. 2, Rainfall 8 days after application of fertiliser) the leaching patterns for the two formulations were not different, with losses increasing with increasing rainfall – though negligible in real terms. These results, although laboratory based do challenge the commonly held belief that the yellowing observed in many cereal crops following heavy rainfall events are due to leaching.

The behaviour patterns observed for both prilled and tableted AN (Figures 1 and 2) appear to qualify the current extension recommendations of only surface applying N fertilisers after rainfall so as to save on time spent on applying and incorporating fertiliser during a time of peak labour demand.

2. On-farm trials

2.1 Rainfall

Rainfall varied in distribution and amount in the three years of the study (Fig. 3). The rainfall season started late in 2005/06 with November receiving the lowest rains. The total rainfall of 703 mm is above the yearly average for the two districts which range from 550 to 600 mm. The highest rainfall was received in December with the rains more or less uniformly distributed across the last three months. Although the 2006/07 rainy season started early, it received the lowest rainfall of the three seasons in this study with a total of 403 mm (Fig. 3). This season was declared a drought year due to severe dry

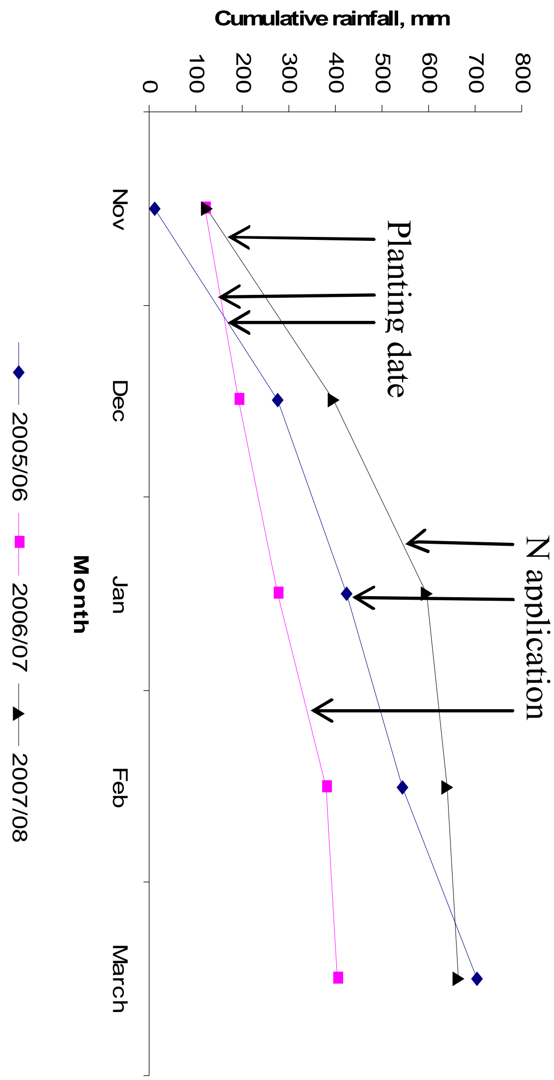

Figure. 3 Timing of planting and nitrogen fertilisation, averaged across trial sites in Masvingo, for the three seasons of study (2005-2008) in relation to average cumulative monthly rainfall distribution between November and March.

spells and low rainfall (FAO Special Report, 2007). The third cropping season was characterized by high rainfall between November and December (Fig. 3). However, the following months had low rainfall resulting in poor distribution of the 665 mm of rain received in this season. These differences in rainfall distribution among seasons affected timing of field operations such as planting of maize and application of AN (Fig. 3). Planting was done early when November received high rainfall as was the case in the 2007/08 season. In all seasons, planting of maize in planting basins was carried about a week earlier than in the flat. Application of AN followed the same trend as planting (Fig. 3).

Resource use and productivity

Basal fertiliser management

In the first year of the study, less than 20% of farmers applied a basal fertiliser on the flat and none of these combined manure with compound D (Table 3). According to Kamanga *et al* (2001) farmers in semi-arid areas base their decision to apply fertiliser on moisture status and their forecasts of the growing season. The 2005/06 cropping season was characterized by low rainfall in November and early part of December (Fig. 3) such that it is likely that farmers decided not to apply any fertiliser as a way of avoiding risk of losing fertiliser in the event of crop failure. In contrast, 71% of farmers applied manure in basins and 33% used the inorganic basal fertiliser with about 10% of these farmers following the CA recommendation of combining the two basal fertilisers. The following seasons received high rainfall in November (Fig. 3) and to take advantage of this the number of farmers applying basal fertiliser in both tillage practices increased (Table 3). As farmers gained experience in fertiliser use, more farmers were willing to apply both manure and compound D and were observed using some of the basin nutrient management practices on their ploughed fields.

Table 3. Percentage of farmers that applied manure and / or Compound D fertiliser on farmer tillage practice and planting basin N tablet trials in Masvingo over the three seasons of study.

Season (Number of on farm trials implemented)	Tillage					
	Flat (%)			Basin (%)		
	Manure	Compound D	Both	Manure	Compound D	Both
2005/06 (29 females, 8 males)	15	20	0	71	33	10
2006/07 (22 females, 6 males)	89	44	33	93	50	43
2007/08 (18 females, 9 males).	95	45	45	100	43	43
Mean	66	36	26	88	42	32

Grain yield

The application of 28 kg N ha^{-1} of either prill or tablet AN significantly ($P < 0.001$) increased maize grain yield by above 40 % in all three seasons in basin tillage and in 2005/06 and 2007/08 cropping seasons on the flat (Table 4). This is in agreement with results obtained by Twomlow *et al.* (2010) from wide scale testing of application of low amounts of N fertiliser (17 kg N ha^{-1}) on farmers fields in dry areas of Zimbabwe. Cereal yield averaged for a broad spectrum of soil, farmer management and seasonal climate conditions increased from 1054 kg ha^{-1} for unfertilized controls to more than 1494 kg ha^{-1} for micro dosed plots. Poor soil fertility is one of the main constraints to crop production in smallholder agriculture in southern Africa (Twomlow *et al*., 2006a). The soils in both Chivi and Masvingo are inherently poor in N (Table 1) and, hence, maize responded strongly to addition of AN fertiliser resulting in high maize yields. The lack of a significant response to micro-dosing in the flat 2006/07 season is due to poor rainfall distribution (Fig. 3) which resulted in low fertiliser use efficiency. Planting basins with their initial water harvesting properties, and higher infiltration rates throughout the cropping season, as observed by Mupangwa for a range of soil (2008), probably improved N use efficiency resulting in the differences observed between control and micro-dosing treatments. However, it is not possible to make valid statistical comparisons between the flat plots and the planting basins because of preferential application of basal fertilizer farmer chose to make on the basin plots in years 2 and 3 of the study (Table 3). The importance of additions of small quantities of N is underlined when the additional maize grain yield obtained by a household is calculated (Table 5). When it is considered that an adult consumes 150 kg of cereal per year (Ncube *et al.,* 2009), then micro-dosing in combination with basins resulted in increased household food security, as even in the driest year of the study at least 900 kg of additional maize grain was obtained (Table 5). This is contrast to the flat plots that showed no significant yield increases to micro-dosing in the dry 2006/07 season, possible due to the later planting dates and a lack of basal soil fertility amendments.

In the flat plots, there was no significant difference in maize yield between the two AN formulations in all seasons (Table 4). However, maize grown in planting basins that received tablet AN significantly ($P < 0.001$) out yielded prill AN by 19% in 2005/06 season. The reason for this difference is, however, not clear. Based on the results of this study, if the cost of purchasing the two AN formulations is similar then tablets may be the less time-consuming and more precise option for applying small quantities of AN fertiliser by smallholder farmers in both the flat and basin tillage practices. However, further work is required to assess the savings in labour that might be attributed to the use of tablets.

Table 4. The effect of applying small doses of prill and tablet ammonium nitrate (28 kg N ha^{-1}) formulations on average maize grain yield (kg ha^{-1}) in the flat and basin tillage systems compared to unfertilized controls in Masvingo over three cropping seasons from 2005 to 2008. (N= number of on-farm trials successfully implemented and harvested each season)

		Seasonal Maize Grain Yield (kg ha^{-1})		
Tillage	AN formulation	2005/06 (N= 21)	2006/07 (N= 16)	2007/08 (N= 27)
Flat	Control	1 953	783	591
	Prill	3 206	836	1 722
	Tablet	3 190	883	1 571
	s.e.d	216.2***	330.7	232.5***
Basin	Control	2 429	1 403	1 348
	Prill	3 560	2 299	3 373
	Tablet	4 239	2 748	3 122
	s.e.d	251.3***	289.0***	201.7***

Means in columns significantly different at $P < 0.05^{*}$; $P < 0.01^{**}$ and $P < 0.001^{***}$

Table 5. Additional maize grain yield (kg ha^{-1}) obtained from applying small doses of prill and tablet ammonium nitrate (28 kg N ha^{-1}) formulations from the flat and basin tillage systems compared to unfertilised controls in Masvingo over three cropping seasons from 2005 to 2008. (N= number of on-farm trials successfully implemented and harvested each season)

		Seasonal Maize Grain Yield (kg ha^{-1}) increase over the unfertilised control		
Tillage	AN formulation	2005/06 (N= 21)	2006/07 (N= 16)	2007/08 (N= 27)
Flat	Prill	1 253	53	1 131
	Tablet	1 237	100	980
	s.e.d	258.4	262.8	189.7
Basin	Prill	1 131	896	2 025
	Tablet	1 810	1 345	1 774
	s.e.d	254.5	133.8*	174.2

Means in columns significantly different at $P < 0.05^{*}$; $P < 0.01^{**}$ and $P < 0.001^{***}$

Agronomic nitrogen use efficiency

In the flat practice agronomic nitrogen use efficiency (ANUE) did not differ significantly between the two AN formulations in 2005/06 and 2006/07 cropping seasons (Table 6). Agronomic N use efficiency was not calculated for the third season as farmers did not consistently collect data on soil fertility amendments due to the on-going national elections In the first season ANUE was above 30 kg maize grain N kg applied ha^{-1}. Kamanga *et al.* (2001) measured ANUE values of up to 80 kg maize grain N kg applied ha^{-1} when below 20 kg N ha^{-1} was applied on sandy loams in Masvingo district in the 2000/01 season. According to Mushayi *et al.* (1998) low ANUE values on farmers' fields were strongly related to other limiting nutrients such as phosphorus. Results from the soil analysis show that some of the fields had low total soil P (Table 1) which may require application of potash. The low ANUE (below 10 kg maize grain N kg applied ha^{-1}) obtained in 2006/07 is probably due to the low and erratic rain received in this season (Fig. 3). Since N-use efficiency is usually a function of time of application (Kamanga *et al.,* 2001) the delay in AN application in 2006/07 (Fig. 3) and low soil moisture probably resulted in low N uptake and utilization by the maize crop. The same trends outlined above were observed in the planting basin (Table 6). However, the ANUE values in planting basins were generally higher than those observed in the flat pointing to improved N efficiency in this conservation tillage practice.

Table 6. The effect of applying small doses of prill and tablet ammonium nitrate (28 kg N ha^{-1}) formulations on Agronomic Nitrogen Use Efficiency (kg of grain ha^{-1} / kg of N applied ha^{-1}) in the flat and basin tillage systems in Masvingo over two cropping seasons from 2005 to 2007. (N= number of on-farm trials successfully implemented and harvested in each season)

		Seasonal Agronomic Nitrogen Use Efficiency (kg of grain ha^{-1} / kg of N applied ha^{-1})	
Tillage	AN formulation	2005/06 (N= 21)	2006/07 (N= 16)
Flat	Prill	33.5	7.5
	Tablet	35.5	6.3
	s.e.d	7.05	1.58
Basin	Prill	22.7	16.5
	Tablet	37.7	23.0
	s.e.d	7.62	3.3

Rainwater productivity

On the flat, applying small quantities of AN fertiliser significantly ($P < 0.001$) increased rainwater productivity in the first and last seasons of the study (Table 7). The same trend was observed in the drier 2006/07 cropping season. There were no significant differences between prill and tablet AN formulations (Table 7). The values for rainwater productivity in this study are close to the range of 1.5 to 4 kg ha^{-1} mm^{-1} reported by Steiner & Rockstrom (2003) in ploughed fields in Tanzania. Addition of N fertiliser improves the efficiency of water use through increased development of leaf area and root system which allows the crop to extract more water from the sub-soil. In the planting basins, significantly "more crop per drop of water" was obtained in all three seasons when 28 kg N ha^{-1} was applied in combination with the preferential application of available basal soil fertility amendments (Table 7). In all seasons, rainwater productivity values were above 3 kg ha^{-1} mm^{-1} where fertiliser was applied including 2006/07 which had low and erratic rainfall (Fig. 3). These results suggest that managing soil fertility and water simultaneously leads to improved resource productivity and high yields. According to Rockstrom *et al.* (2003) results from field data in Kenya showed that the full benefits of water harvesting can be met through addressing soil fertility management. Thus conservation agriculture techniques such as planting basins are one method of improving maize productivity in semi-arid smallholder agriculture.

As was observed with yield data in basins in 2005/06 season (Table 4), the tablet AN formulation was associated with a significantly ($P < 0.001$) higher rainwater productivity than prill AN (Table 7). Therefore, in this season maize plants grown under planting basins and received AN tablets were more effective at using the available soil water than plants that received prill AN and this translated to statistically higher maize grain yield. This trend was however, not apparent in the subsequent seasons when the same dose of tablets was applied to the same basin.

Table 7. Response of rain water productivity (WP_{rain}) (kg of grain ha^{-1} mm of $rain^{-1}$) to applying small doses of prill and tablet ammonium nitrate (28 kg N ha^{-1}) formulations in the flat and basin tillage systems in Masvingo over three cropping seasons from 2005 to 2008 compared to unfertilized controls. (N= number of on-farm trials successfully implemented and harvested in each season)

		Seasonal Rain Water Productivity (kg of grain ha^{-1} mm $rain^{-1}$)		
Tillage	AN formulation	2005/06 (N= 21)	2006/07 (N= 16)	2007/08 (N= 27)
Flat	Control	2.80	1.61	0.91
	Prill	4.58	1.81	2.59
	Tablet	4.61	1.82	2.43
	s.e.d	0.327***	0.717	0.386***
Basin	Control	3.68	1.86	2.00
	Prill	5.15	3.61	5.00
	Tablet	6.88	4.01	4.52
	s.e.d	0.609***	0.578**	0.320***

CONCLUSION

AN tablets are a viable alternative to prill AN as a means of increasing cereal productivity in semi-arid area using the micro-dosing technology. Results from this study show that the tablets can maintain their integrity despite rough handling. However, some form of vibration tests maybe more indicative of the impacts of potential transport along rural roads.The N content in the tablets (33.3 %) was comparable to that in prill AN (34.6%). However, the tablet formulation took twice as long to dissolve as prill AN when placed on a wet soil. Despite this difference in solubility, simple break through tests using leaching columns filled with a coarse granitic sandy soil, typical of the smallholder sector in Zimbabwe, suggest that less than 2% of the total AN applied was lost due to leaching in these nutrient depleted soils after a 50 mm simulated rainfall event. Whether this laboratory observation can be directly translated to the field is open to questions, but the results do suggest that field studies are required to explore this behaviour further. Although less soluble than prill AN there was no significant difference in grain yield between the two AN formulations as both significantly increased maize grain yield over the control. In fact in the first season, the tableted AN had significantly ($P<0.001$) higher rainwater productivity and grain yield than prill AN. In addition, yield benefits to micro-dosing can be maximized by combining it with better water management techniques such as planting basins, as the host farmers chose to do in the second and third seasons. Hence, if AN tablets are available at a price comparable to prill AN they can be a more precise method of micro-dosing cereal crops by smallholders.

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