Effects of Fertilisers on Seed Germination in New Zealand

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Abstract

This paper uses data from a series of local field and glasshouse studies to highlight the main issues associated with fertilisers causing germination damage to seed. When fertiliser was placed in close contact with seed either through a conventional drill or when placed on top of seed in the glasshouse, in general small seed was more predisposed to germination damage than large seeds. The greatest risk was when using clover and Brassica seeds. Urea and borated fertilisers cause the most damage, while high analysis DAP and MAP based fertilisers, in particular those containing more ammonium N caused more damage than Superphosphate based treatments. Damage increased with increasing fertiliser rate. Where yield was measured plants usually had the ability to compensate for 15-30% damage, particularly those crops that respond to N. Soil moisture status had a large influence on germination risk, in moist soils damage was much less than in dry soils. When soils were wet after a prolonged dry period, some delayed germination occurred but this was less than if moisture was adequate from the start. Broadcasting fertiliser in contact with seed caused minimal germination damage provided contact time was kept to a minimum. Some recommendations are given.

Additional key words: *germination damage, fertiliser damage, osmotic pressure, salt index, ammonium N*

Introduction

Agricultural consultants still have difficulty in deciding appropriate fertilisers and application rates to use with seed to minimise the risk of germination damage. This is not new, as early as 1928 fertiliser effects on germination were examined in New Zealand on brassica greenfeed crops (Hudson *et al.,* 1937). Their work showed that traditional turnip fertilisers which contained small amounts of ammonium sulphate and potassium chloride added to superphosphate caused more germination damage to turnips than superphosphate, particularly when premixed for prolonged periods with seed. In turn superphosphate was more risky than various lime: superphosphate mixes. The proportions of lime to superphosphate, the type, the source and fineness of agricultural lime, the moisture content of the product and the soil after drilling all played a part in the effectiveness of a fertiliser treatment. Partly as a consequence of this Reverted Superphosphate was developed whereby 10-25% lime was reacted with superphosphate during manufacture to temporarily reduce the water soluble phosphorus (P) in the product and reduce the risk of fertiliser damage to seed. Other products developed by the New Zealand fertiliser industry included Basic Superphosphate (10% slaked lime addition to superphosphate) as this was seen as a better way of controlling the degree of P reversion and Serpentine Super. Serpentine was widely used as an alternative to lime. Another common product used for brassicas was 'Turnip and Rape' initially a blood and bone, sodium chloride mixture with superphosphate sometimes also containing potassium chloride (Arthur Duncan, pers. comm.). These were later replaced by a weak (10%) ammonium sulphate reverted superphosphate or superphosphate mix. During this period there was little research in New Zealand on fertiliser effects on seed germination and most products were developed from crop observation studies. In the 1980's products such as Longlife Super (67% Superphosphate cogranulated with 33% RPR) were developed as cost effective pastoral alternatives to Superphosphate. Longlife Super had a lower water soluble P content than superphosphate and Hayward and Scott (1993) demonstrated that it could satisfactorily replace Lime Reverted Super as a drilling fertiliser for turnips.

More concentrated fertilisers based on DAP and MAP, Nitrophoska and urea have been readily available alternatives to Superphosphate based products since the late 1960's. These products have been increasingly used for drilling a wide range of crops due to their N content and some have been found to pose a significant risk to seed germination. These fertilisers highlight the two main effects of fertilisers on germination (Dowling 1996; Olsen and Drier 1956). Firstly there is an increased risk associated with products that produce ammonia, such as urea, DAP and ammonium sulphate. The second effect is caused by the salt effect of the fertiliser generating an osmotic pressure when the fertiliser dissolves near the seed. Fertilisers such as DAP and MAP can generate high salt concentration compared to Superphosphate based materials. The hygroscopic nature of some fertilisers is also important. DAP is known to be quite hygroscopic drawing moisture from the seed and making it more at risk from dessication and fungal damage. Since fertilisers that generate ammonia also exert an osmotic pressure and many blended fertilisers contain a combination of chemicals it is not possible to grade fertilisers based solely on one of these mechanisms.

As well as the type and rate of fertiliser, there are other factors that influence the germination risk. These include the proximity (or placement) of seed relative to fertiliser, the soil moisture conditions, the soil texture and pH, and the plant species (Carter 1967; 1969). To cover the 'worse case scenario' many recommendations have tended to be conservative with the consequence that many farmers and consultants become complacent as to the risk. While we can draw on overseas experience, New Zealand farming practices are often unique due to locally produced combine drills and fertiliser products, different application rates and often different crop species. With this in mind Ravensdown Fertiliser Co-operative staff undertook a range of field and glasshouse trials covering a range of fertiliser products, rates, fertiliser placement, and crop species. This paper uses some of this data to discuss the main issues associated with seed and fertiliser damage with a view to giving some guidelines to the risks associated with various product and crop scenarios.

Materials and Methods

The work cited here was carried out in both the glasshouse and in the field. A general description of the fertiliser products examined in these studies and their approximate salt index is given in Table 1.

Glasshouse Trials

These were carried out at Ravensdown Fertiliser Co-op Ltd's, Hornby manufacturing plant, Christchurch in 1989/90 and 1990/91. Fertiliser treatments were applied in furrows to trays 50mm deep, 1m x 1m in dimension. Each furrow was an attempt to mimic the fertiliser placement relative to seed occurring in combine drills used at the time. The fertiliser used was rolled through a 2mm sieve so that there were no large granules present and spread evenly down the row. Seed, usually 20 seeds/row was placed directly on top of the fertiliser and covered with soil. The soil for the early trials was a Templeton silt loam of high fertility (pH 6.1, Ca 10, Olsen P 39, K 6, SO_4-S 56, Mg 19, Na 30). Pea trials in 1990/91 were on a similar soil (pH 6.3, Ca 16, Olsen P 30, K11, SO_4-S 80, Mg 32, Na 11, soluble salts 0.08%). Each treatment was replicated three times under two different moisture regimes, 'wet' where the soil moisture was kept as close as possible to field capacity and 'dry' where soil was maintained just above wilting point.

Field Trials

Most field trials were undertaken at Ravensdown Fertiliser Co-op Ltd.'s Seadown Farm in South Canterbury in the early 1990's. These were on free draining Lismore stony silt loams with spray irrigation. Trials were allocated to different paddocks as dictated by the crop type to be examined and the crop rotation. All paddocks had good fertility, typically pH 5.7-6.3, Ca 6-9, Olsen P 18-30, K 5-10, SO_4-S 5-15, Mg 15-20, Na 4-7. Early trials were carried out using an experimental 7 coulter Massey combine drill, with two large boxes, one box for fertiliser and one for seed. A third small seed box was used for brassica and clover trials. Later trials were carried out with a 9 coulter experimental Agrow drill with two large boxes. This had finer rate control and by closing half the outlets in one box or by changing a plate a range of seeds from small brassicas and clover to peas could be adequately drilled. With both drills, seed and fertiliser fell down tubes which met at the coulter so that seed and fertiliser fell in the furrow together. This was typical of the majority of drills used in New Zealand at the time. The fineness of the seed bed dictated the degree of initial contact. All trials were replicated, plots were a single pass wide (1.05 or 1.35m) and ranged in length from 20m to 50m. Germination was either measured by multiple readings of a length of row, and/or by scoring the establishment and later the vigour of the crop. In some trials crops were taken through to harvest and plot yields are also given, however this was often impractical due to interactions with weeds and fertiliser where side dressing N was desirable to carry the crop through to harvest.

Data from a barley trial carried out at Methven using a Planet Junior drill with seed and fertiliser premixed is also used. The site was a borderdyke irrigated Lyndhurst stony silt loam. Greenfeed brassica rape results are also compared with those of Geoff Hayward undertaken at Lincoln (on a Templeton silt loam), work sponsored by Ravensdown Fertiliser Co-op Ltd. and where similar treatments were used. Full details of this work are given in Hayward and Scott (1993).

Results and Discussion

Plant species by fertiliser interactions

It is not easy to make simple recommendations on fertiliser safety with seed as the risk associated with a fertiliser varies among plant species. To demonstrate this a series of glasshouse trials involving the effect of a range of Superphosphate based fertilisers and DAP, on the germination of brassica rape seed, perennial ryegrass and white clover, can be used, Figure 1. At a constant rate of P (15kg/ha) no fertiliser seriously reduced the germination of perennial ryegrass and only DAP significantly reduced the germination of rape seed. By contrast even Superphosphate had some effect on white clover with only the three Superphosphate based fertilisers, Longlife Super, Lime Reverted Super and 50:50 Super:Phosphate Rock having minimal effect. These three products contain less water soluble P than superphosphate so they generate a lower osmotic pressure in solution. DAP has the greatest effect on all three species because it not only generates a higher osmotic pressure but also contains ammoniacal N. When the same treatments are applied at a constant rate of fertiliser product, (163kg/ha) the product supplying less P (lime reverted super) generally caused similar or slightly less damage (data not presented). In contrast DAP which supplied more than 30kgP/ha at this application rate and so generated a higher osmotic pressure, caused more damage to rape seed and white clover. However there was little extra damage to ryegrass seed highlighting the variability with species and rate.

A comparison of the effect on germination damage of DAP and MAP on these three species and field peas, is demonstrated in Figure 2. The response to DAP was similar to that previously observed, despite the slightly higher P rate (20kg/ha) used and peas despite their large seed size performed intermediate between ryegrass and rape seed. Germination was poorer than in the first experiments, probably due to higher soil and air temperatures and perhaps more short term moisture stress in the glasshouse in summer indicating that climatic conditions can play an important part in the severity of damage. Perhaps surprisingly, when used at similar amounts of P there was little difference between MAP and DAP. Other studies (Allred and Ohlrogge 1964; Dowling 2001a; Olsen and Drier 1956) suggest DAP will cause more risk as it contains more ammonium N plus its reaction in the soil is basic so it generates free ammonia which MAP does not (Rob Sherlock pers. comm.). It is unlikely that the higher osmotic pressure generated in soil solution by MAP at equal application rates counteracts the ammonium effect as there is not a great difference in salt index between the two products (Table 1.). This is supported by studies of Dowling 2001b. Dowling (1996) isolated ammonium from osmotic effects in wheat, oil seed rape (canola) and chick peas and found in the absence of high ammonium concentration all species responded similarly to increasing osmotic pressure but oil seed rape and wheat were more sensitive to ammonium than chickpeas. In this work rape seed was more affected by the two fertilisers than field peas reinforcing his conclusions.

Peas have also been examined in the field with DAP and MAP at higher P rates, 26kg and 40kgP/ha (data not presented). Again both fertilisers reduced germination, although at the lower P rate, the result was less significant than in the glasshouse. In the field it is likely that some soil falls between seed and fertiliser and reduces direct contact in the furrow although it is still possible that free ammonia can easily diffuse to the seed, particularly in sandy soils (Allred and Ohlrogge 1964). Again there was also little difference between the two fertilisers, perhaps supporting Dowling's observation that chickpeas are less affected by ammonium than some other species. This could simply be a reflection of pea size relative to the localised soil concentration of ammonia.

Soil moisture

The literature widely highlights the importance of adequate soil moisture in reducing the risk of fertiliser damage to seed (Carter 1969; Deibert 1994; Olsen and Drier 1956), yet the seasonal or regional weather conditions are often overlooked by advisers when making recommendations. The glasshouse trials (Figures 1 and 2) used two moisture regimes, one where the soil was kept as close as feasible to field capacity and the other where the soil remained much drier but above wilting point. The mean results (mean of all fertiliser treatments for two moisture regimes) are summarised in Table 2 and clearly show the overriding effect of moisture on germination, particularly when using MAP and DAP based fertilisers. White clover is the most susceptible species followed by rape seed, clearly showing it is not advisable to apply either fertiliser through the drill irrespective of moisture status. Peas, despite their size are affected by high analysis fertilisers but only if the conditions are dry. For this reason while high analysis fertilisers are used with peas the rates recommended are strictly controlled to minimise risk. Perennial ryegrass in contrast is quite tolerant of fertilisers in close proximity to seed irrespective of moisture conditions. Carter (1967) found in Australian conditions ryegrass was the most tolerant to a range of fertilisers but sub clover was less susceptible than brassica seeds. It is important to recognise that fertilisers may not necessarily prevent germination but may simply delay emergence, or reduce vigour (Chapin and Smith 1960). This was noted in most glasshouse trials and is best highlighted in a swede seed trial involving no fertiliser but under three moistures regimes, moist (near field capacity), dry (slightly above wilting point) and dry then moist, (Table 3). Chapin and Smith (1960) found with wheat at different levels of moisture as stress increased the initial response was to delay germination but as the moisture stress increased the rate at which the delay occurred decreased until finally germination was prevented altogether. Nitrogen had a greater effect than potassium (K). Hence in the field when crops are sown in dry conditions when it finally rains germination can occur, albeit at a reduced emergence. However this brings agronomic problems in that the crop will be of differing maturity often causing problems at harvest and in the case of greenfeed making it difficult to ascertain when it is safe to graze the crop. Further, weeds have more opportunity to infest the crop leading to greater weed management during the season. The worst conditions in which to sow seed are conditions with sufficient moisture for seed germination seed but without adequate follow up moisture to sustain growth. Hence moist or initially very dry conditions are the best scenarios (Olsen and Drier 1956).

Species Data

Small Seed While results indicate clover is very susceptible to fertiliser damage, even at times from superphosphate, the work of Dowling (2001?) with sub clover compared to brassicas suggests there may be species differences as well. Certainly the hardness of subclover seed would suggest soil osmotic pressure is likely to have dropped before germination necessarily occurred with hard seeded crops. With regard to other legume species, one further pot trial undertaken by Ravensdown staff (J. Jordan pers. comm.) in the early 1980's, showed bare lucerne seed was not adversely affected by 250kg/ha of Superphosphate (74% water soluble P) compared to 500kg/ha provided the pots were kept near field capacity. Where the pots were not subsequently rewatered germination at both rates germination was further halved.

Since that time Superphosphate have consistently had much higher water soluble P content (>85% wsp, Table 1) and therefore today the risk of damage would be greater, particularly under marginal moisture conditions. Superphosphate can also contain high but variable amounts of water soluble fluorine. Overseas, this has been ascribed as the reason for variable damage between different superphosphates in wheat (Kunra *et al.* 1962). Paul comment.

The response of an annual ryegrass and rape seed in the field at 20kgP/ha (Figure 3) was similar for Super and Longlife to that in the glasshouse (Figure 1.) but not for lime reverted super. Grass seed germination was also more affected for DAP, possibly due to the weather conditions. The work of Hayward and Scott (1993) on rape seed shows very similar results (Table 4) for these products. The relatively poor performance of Lime Reverted Super compared to the glasshouse results is possibly because the product at the time was dry blended and having minimal effect on P solubility. Lime or serpentine reverted Super are now made the more conventional way by addition ex den to soak up any free sulphuric acid, ensuring there is less water soluble P available in the short term. Serpentine has now largely replaced lime as the preferred reversion agent (typically 40% wsp for Serpentine Super, Ravensdown product specifications). Although a product such as Longlife Super has Reactive Phosphate rock added ex den the finer portions of which will soak up free acid, it is likely to simply perform better than Super through dilution of soluble P. All trials confirm that Longlife Super is a satisfactory replacement for Lime Reverted Super for ryegrass and rape seed, at least at rates up to 20kgP/ha. Equally other P rock or Super mixes may achieve a similar result and the osmotic pressure can also be reduced by reducing the fertiliser application rate of Super. The concern with sowing new pasture where grass and legumes are mixed is the performance of the clover even Longlife Super could be marginal and in dry conditions the best option may be to drill lower application rates, preferably use lower water soluble P fertilisers and broadcast any balance of P required. It is still important at Olsen P values <15 to apply at least 10kgP/ha in close proximity to seed to prevent production losses.

Although DAP can sometimes reduce ryegrass germination at 20kgP/ha and at 15-20kgP/ha with rape seed (Figures 1, 3, Table 4) it is its mixture with ammonium sulphate to make Cropmaster 20 that causes significant damage. This product contains more than twice the amount of ammonium N when applied at the same P application rate. Reducing application rate (Figure 3.) helped minimise the difference although at this rate it still applied slightly more ammonium N and has a slightly higher salt index than straight DAP. Products such as this now dominate the New Zealand high analysis market and Olsen and Drier (1956) also faces similar issues with similar products overseas. Nitrophoska 12-10-10 of a higher salt index performed slightly but not significantly better than Cropmaster 20 with rape seed (Figure 4). In the same experiment a low rate of urea (32kgN/ha) while causing significant damage was no worse than Cropmaster 20 or Nitrophoska 12-10-10. Hence with small seeds in order to provide sufficient P, straight DAP (or MAP) can be better products to drill and if more N is required it should be topdressed. Unfortunately farmers like to drill Cropmaster 20, particularly when direct drilling. In these cases rates should be reduced, overseas data for more tolerant small grains would suggest no more than 60-90kg/ha of these type of product be used (Olsen and Drier 1956). If straight grass were sown, and in practice farmers often use 125kg/ha or higher.

Peas The response of peas to DAP (or MAP) is somewhat intermediate between ryegrass and rape seed (Figure 2.). In the field it was also compared to Cropmaster 15 which also significantly reduces plant establishment when drilled (Figure 5) as did a similar product Ammophos Hycrop (8-15-15) based on MAP. Despite this there was more than adequate compensatory growth due primarily to a response to the N and yield was not affected unless the rate was increased. Both products have similar salt indexes but Cropmaster 15 contains more ammonium N. In a further trial Cropmaster 15 performed poorer than Ammophos Hycrop 8-15-15 and a MAP special mix Ammophos Hycrop 10 containing some ammonium sulphate performed intermediate between these (data not presented), highlighting that although peas may be less affected by ammonium N than other species it is still important. Overall where N is involved it would seem peas have the ability to compensate for a 10-25% drop in plant population, the greater the compensation at the higher N rates. In response to this Ammophos Hycrop 8-15-15 is not recommended for drilling above 150kg/ha and Cropmaster 15 less, preferably 100kg/ha at which rate not all P crop removal is met.

Cereals The Cropmaster range were designed primarily for winter and spring cereal production. The effect of Cropmaster 15 versus Cropmaster 20 on germination of barley can be seen in Figure 6. Increasing the application rate increases the germination damage ($p<0.001$), especially at the highest rate. Further Cropmaster 20 causes significantly more damage than Cropmaster 15, ($p=0.02$). This is because Cropmaster 20 contains more ammonium sulphate and no potassium chloride, indicating the impact on germination caused by the extra ammonium is greater than the decrease in salt index caused by dropping the potassium chloride from the product. The effect on germination effect is negated over time by the benefits of the extra N supplied through improved tillering of the surviving plants. While conventional drilling rates should be kept below 250kg/ha on these soils and perhaps as low as 180kg/ha, on heavier and wetter soils experience would suggest farmers get away with rates of at least 250kg and often higher without any noticeable effect. Recommendations in the USA and Australia tend to be more conservative, in the order of 60-110kg/ha of product (Deibert 1994; Olsen and Drier 1956; Dowling pers. comm.).

Urea is known to be highly toxic to seed, second only to liquid and anhydrous ammonia (Carter 1969), forms of N not used in New Zealand, as it generates free ammonia. This can be demonstrated in two cereal trials, one on barley showed 25kgN caused no minimal damage (Figure 7), but 50, 75 and 100kgN/ha caused 28%, 49% and 57% reduction respectively. The effect was more severe on wheat (Figure 8) significantly increasing with N rate even at 20kgN/ha ($p<0.009$) and particularly when compared to that of ammonium sulphate ($p<0.001$). While these two trials highlight the extra N provided can compensate for at least 30% reduction in plant population, it is not a very cost effective way to generate yield. As a general rule barley is considered marginally more tolerant of fertiliser than wheat, while oats is considered even more tolerant (Olsen and Drier 1956). Ammonium sulphate nitrate (ASN) which was shown in a rape seed trial (Figure 3) to cause minimal damage at 32kgN/ha also performed better than urea. While it has a higher salt index than urea of more relevance only 70% of its N is in the ammonium form and as such it is likely to perform similarly to ammonium sulphate. In practice urea is not recommended as a planter fertiliser although it is likely with cereals you can get away with 50-60kg/ha urea providing there is adequate soil moisture.

Boron Boron is known to be as highly toxic to seed as urea (Olsen and Drier 1956). In one field trial at Seadown using a Duncan seed drill and using the small seed box, addition of 17kgFB48 (a sodium borate) to 350kg/ha of Nitrogen Super halved the plant population of Swedes.

Overall from a nutrient perspective, this work supports that of others indicating that phosphorus causes less damage than potassium which generates higher salt index which in turn causes less damage than nitrogen fertilisers in particular those generating ammonium. In these trials NP particularly based on DAP cause more damage than NPK.

Placement

Proximity of seed to fertiliser is important in assessing the risk of germination damage. When comparing damage from broadcast versus drilled treatments even highly toxic products such as urea cause negligible damage if broadcast immediately prior to or after drilling (Table 5). This is because the free ammonia or osmotic concentration is lower near the seed than if specifically placed there. As the primary reason for drilling fertiliser is to provide adequate P for plant establishment an optimum of 20-30 is set for field crops (Morton *et al* 2000). Hence when P levels are adequate fertiliser can be broadcast or at least drilling rates can be reduced with the balance broadcast. This enables the use of more risky NPK fertilisers and higher rates of N at time of planting, which suits todays technology as many new drills do not have fertiliser boxes and fertiliser has to be spread anyway. In general P is better incorporated in the final working before drilling than broadcast (Olsen and Drier 1956).

In many situations particularly with sowing greenfeed it is not uncommon to mix seed and fertiliser and spread them by a groundspread truck or by air. Although replicated trials have not been carried out using this approach, experience at Seadown would suggest that even mixing bare forage Brassica seed with 200kg/ha of Cropmaster 20 causes no economic damage provided the mixture is spread immediately. Lamp (1962) demonstrated this was better than contact drilling turnip seed but not as good as precision sowing seed and fertiliser apart. Avoid prolonged contact between seed and fertiliser particularly with hygroscopic fertilisers such as DAP as they not only attract moisture from the atmosphere but they also dessicate the seed. Superphosphate based materials would be more advisable if prolonged contact is unavoidable such as when greenfeed or pasture fertiliser mixes need to be moved great distances before spreading as commonly occurs in the high country. Loads should also be covered and stored undercover, and preferably seed and fertiliser mixed on a load by load basis. In theory coating seed would also protect it from fertiliser damage however Hayward and Scott (1993) found no difference between coated and uncoated brassica seed. Possibly this is because the coating itself readily swells encouraging early germination before dissolving fertiliser has time to be diluted through a greater soil volume.

The technology now exists in some drills for seed and fertiliser to be placed apart. In a maize planter and with the Baker Cross Slot technology developed at Massey University, fertiliser is placed to the side and below the seed so that the emerging roots grow into the fertiliser band. There is anecdotal evidence to suggest with this technology that rates above 250kg/ha of Cropmaster or Ammophos products can be safely drilled with cereals and greenfeed brassicas and perhaps up to 375kg/ha if moisture conditions are good. Maize planters have traditionally used similar technology to apply rates of 200-375kg/ha of products such as Nitrophoska 12-10-10, Cropmaster 15 or 20 or Ammophos 8-15-15. However many fertiliser consultants now restrict maximum rates to 300kg/ha (Willimott pers. comm.), particularly on lower bulk density and drier soils. Much of this may be due to maize being planted in 30cm rows (as are some grass and brassica seed crops) as compared to conventional drills which sow at 15-17cm row spacings. This effectively doubles the fertiliser application rate near the seed (this issue is more extensively explained by Diebert 1994). A ridger is the other commonly used broadacre drill and is used in Southern New Zealand on finely textured soils for planting Swedes and choumoellier. Seed is either applied via a small seed box or is mixed with Superphosphate in the back box, either way the application is near the top of the soil ridge created by the drill but more importantly above a higher concentrated fertiliser such as DAP applied in the front box. Hence there is reduced risk of contact. The greatest concern is when sowing seed and fertiliser using direct drills. As there is little soil disturbance seed and fertiliser will lie close to each other and hence fertiliser rates must be reduced and use of N fertiliser minimised. Unfortunately the circumstances in which they are often used is in extensive drier (and more isolated) environments where moisture conservation is important to apply small seeds and it is important to apply N with the drill to offset the lack of early soil N mineralisation. Ideally drilling N should be kept to no more than 10-15kgN/ha if using DAP based fertilisers or Choudhary (1984) suggested perhaps the better agronomic option is to delay fertiliser application.

Other Factors

This work has not examined other factors such as the effect of fertiliser granule size and soil texture. In theory larger granules pose less risk (unless a seed falls immediately next to a granule) as the osmotic concentration is likely to be less around a seed. Olsen and Drier (1956) demonstrated this on wheat using pelleted vs powdered MAP. In light sandy soils, stony soils and low bulk density (eg. pumice and peat) soils, seed tends to be more at risk from fertiliser damage compared to heavy clay and high anion storage capacity soils where nutrients are more quickly bound to soil colloids so soil solution concentration will more quickly lower (Allred and Ohlrogge 1964).

Conclusions

It is difficult to make precise recommendations as to the relative merits of products as their specific affect reflects so many factors. However we can make some general statements;

1. Small seed are more predisposed to germination risk than large seeds but there are exceptions. In this work in order of susceptibility, clover > rape/brassica seed > peas > ryegrass > wheat > barley. Oats are generally the least susceptible and maize is likely to perform similarly to peas.

2. While germination risk generally increases with increasing salt index and those with phosphate, in particular of low water solubility are the safest, as many products contain more than one nutrient this gets confusing. Of most risk are those containing or quickly generating ammonium N, particularly when using DAP/MAP mixtures with ammonium sulphate. Of the products tested, in order of safety;
   Lime Reverted Super = Longlife Super > Super > Potash Supers > Nitrogen Supers > MAP = DAP > Cropmaster 15 = Nitrophoska 12-10-10 > Cropmaster 20 > Ammonium Sulphate = ASN > Urea or Sodium Borate.
3. Germination risk increases with increasing application rate and product application rates may range from as little as 125kg/ha of Super based products with clover establishment to over 250kg/ha of Cropmaster 20 with cereals with conventional drills. Avoid drilling urea or borated fertilisers with the seed.
4. Lack of moisture is by far the most important determinant of whether fertiliser germination damage will occur. In dry conditions delay sowing until sufficient rain falls or if you cannot wait reduce application rates and if necessary switch from ammonium based fertilisers to Superphosphate based materials.
5. Seed and fertiliser contact can be reduced by using drills that place seed and fertiliser apart or by broadcasting fertiliser. Seed and fertiliser can be mixed together and broadcast provided contact time is minimised. Use exceptionally low rates of N fertiliser in direct drills, eg. below 15kgN/ha (and not as urea) with new pasture and brassicas.

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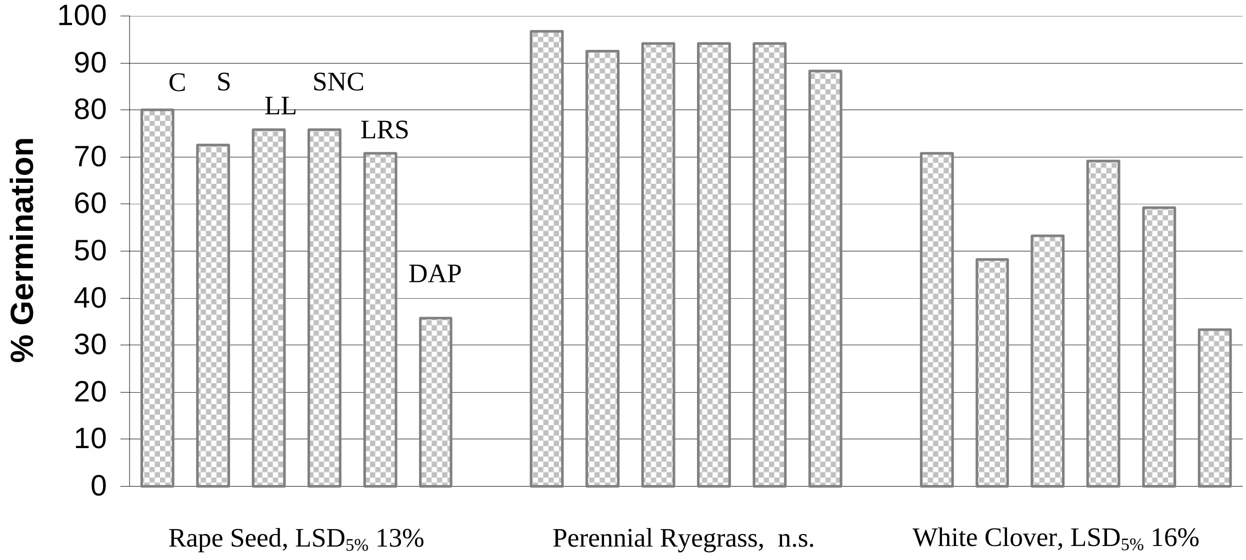


Figure 1. Effect of various fertilisers applied at 15kgP/ha on germination of three species in the glasshouse, mean of two moisture regimes; C-control, S-Super, LL-Longlife Super, SNC-Super/North Carolina Phosphate Rock, LRS-Lime Reverted Super, DAP.

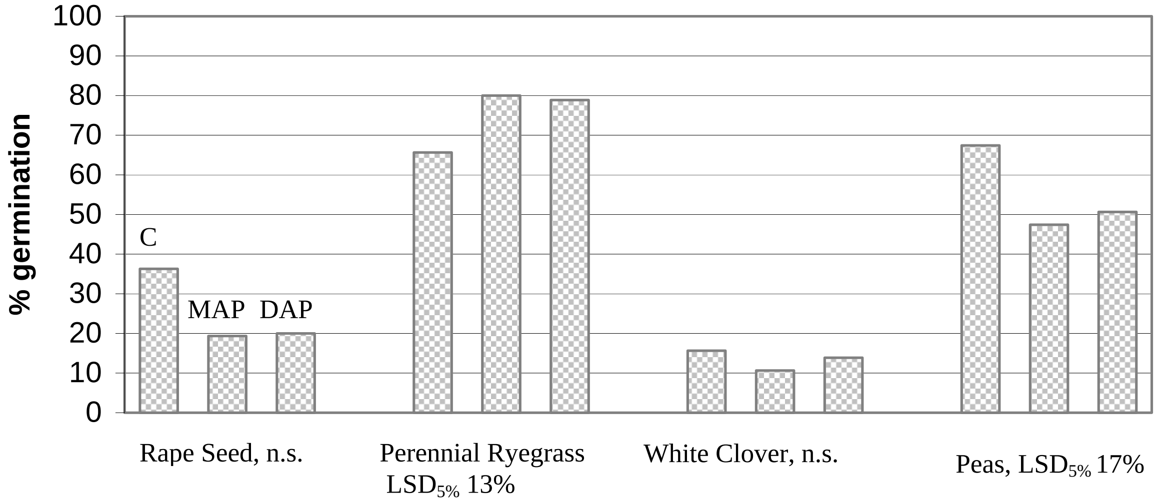


Figure 2. Effect on germination of MAP and DAP applied at 20kgP/ha to four species in the glasshouse, mean of two moisture regimes.

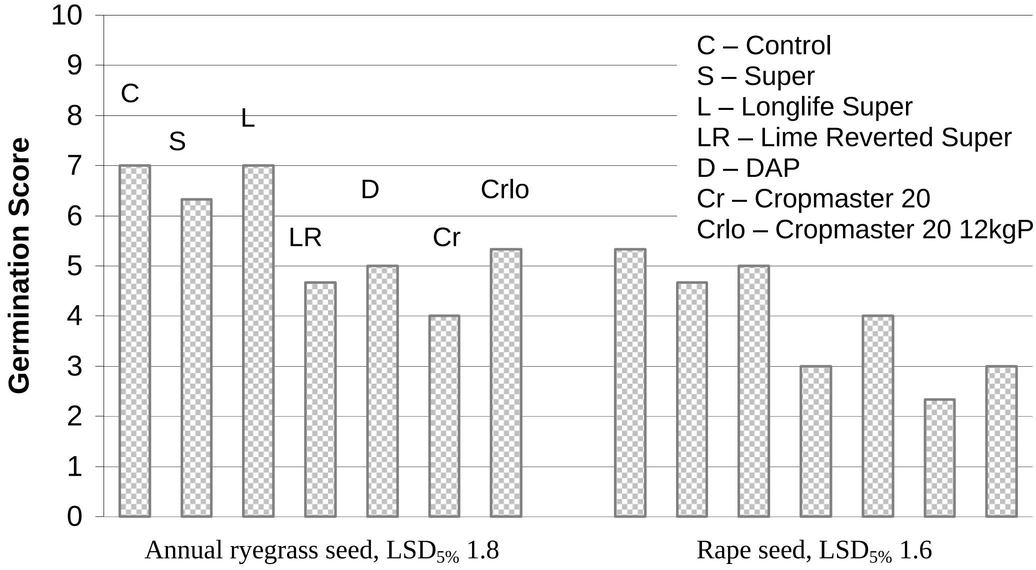
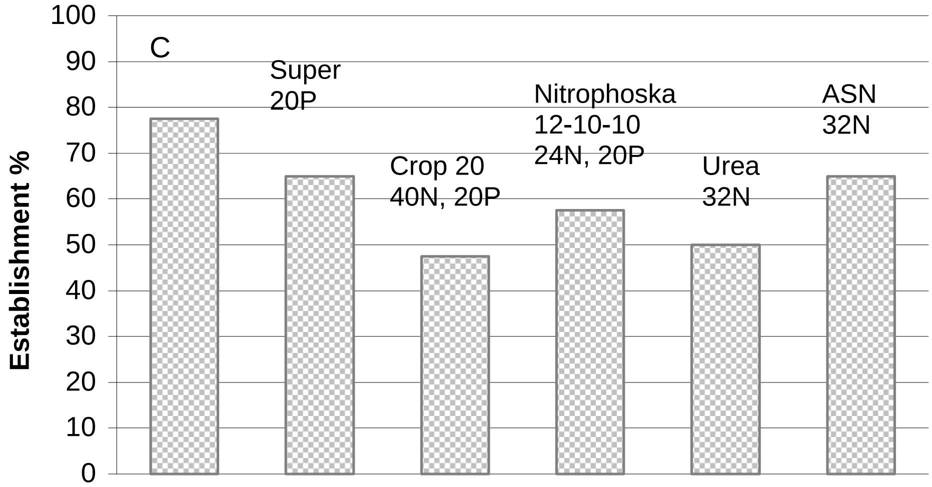


Figure 3. Effect of various fertilisers applied at 20kgP/ha on the germination of ryegrass and rape seed in the field.



$LSD_{5\%}$ 19%

Figure 4. Effect of various fertilisers on the establishment of greenfeed Rape in the field.

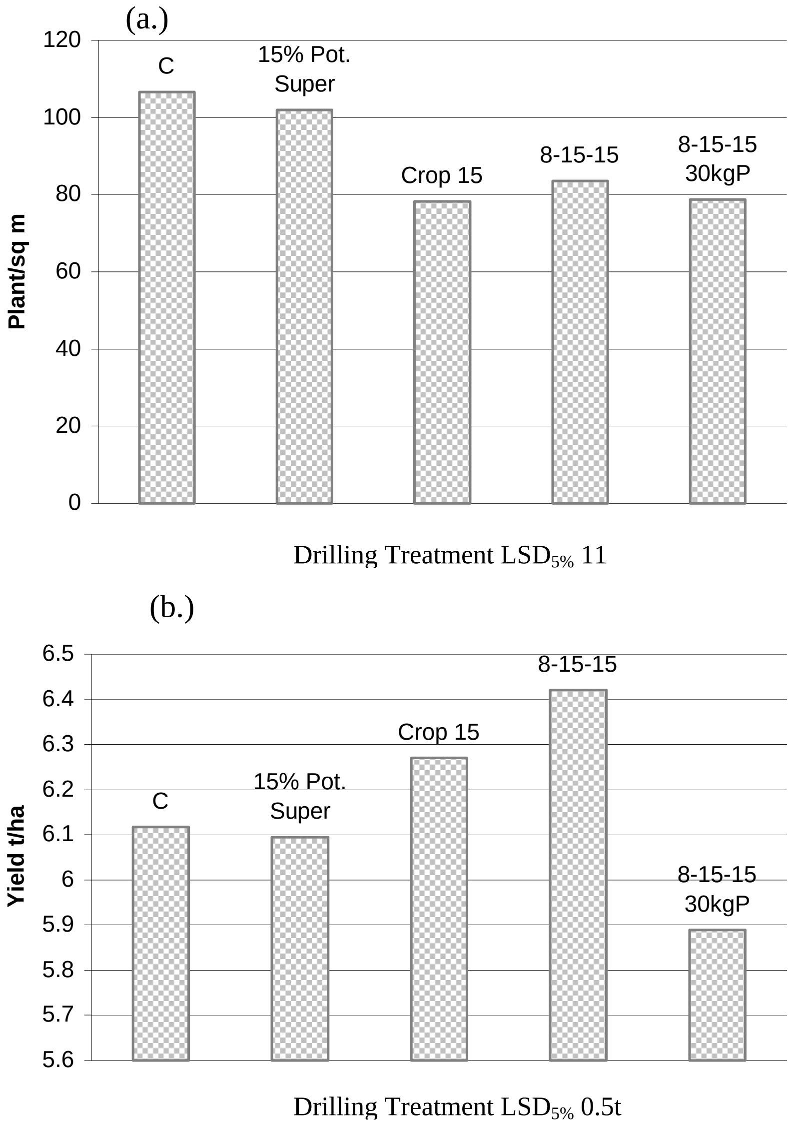


Figure 5. Effect of various drilling fertilisers (applied at 20kgP) on plant establishment (a) and yield (b) of peas in the field.

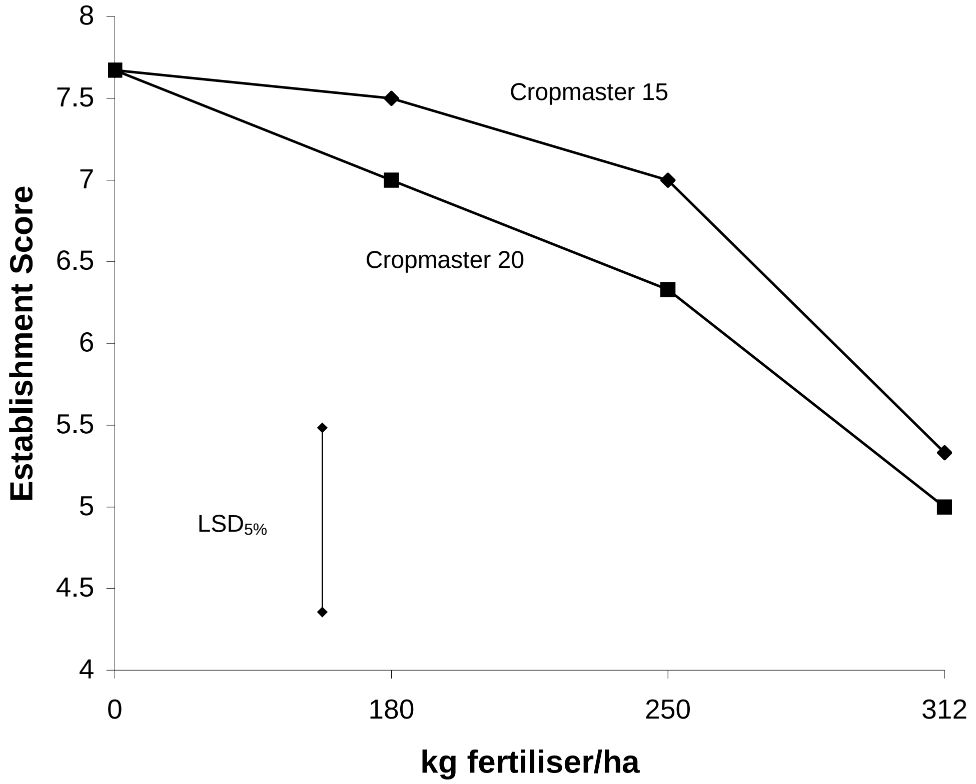


Figure 6. Influence of drilling two DAP based fertilisers on germination of barley in the field.

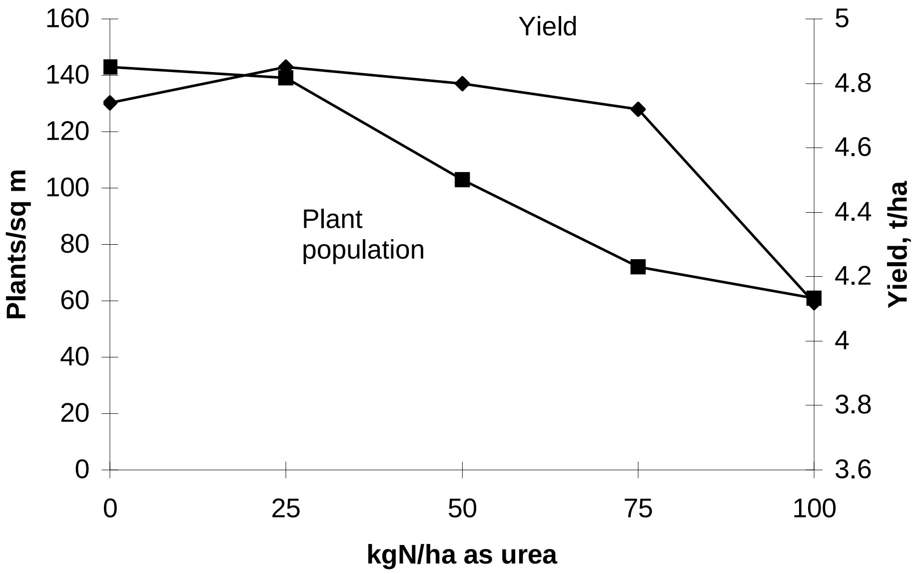


Figure 7. Effect of drilling urea on plant establishment and the resulting yield of barley.

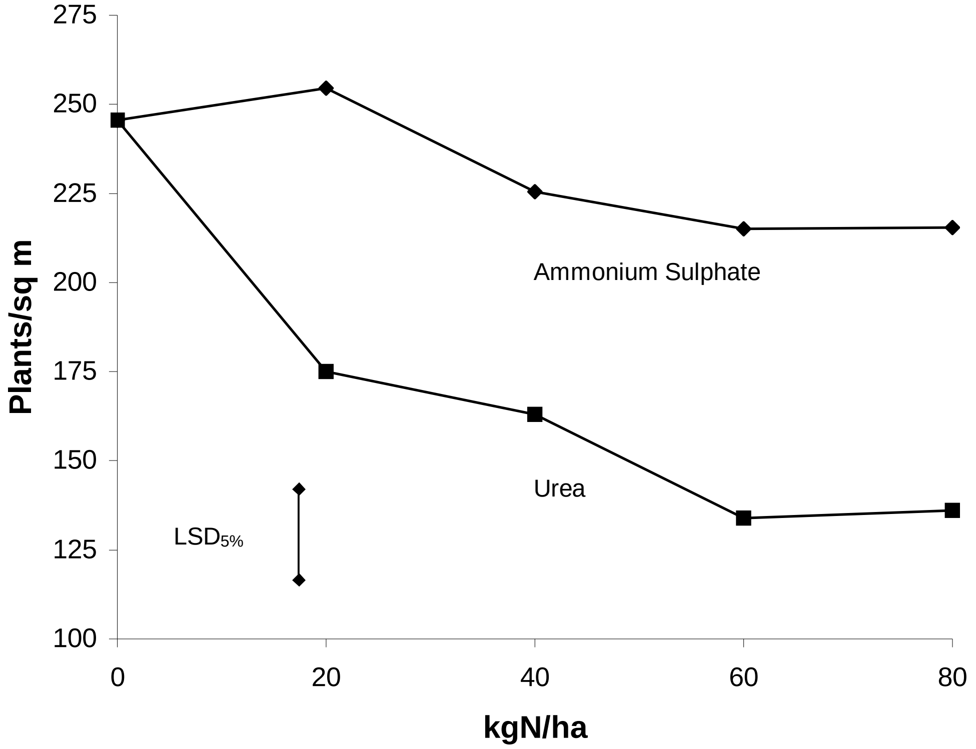


Figure 8. Influence of drilling two nitrogen sources on germination of wheat in the field.

Table 2. Effect of soil moisture on the germination % of four species in various glasshouse trials.

	Peas, trial 1	Peas, trial 2	Rape seed	Perennial Ryegrass	White Clover
High Analysis fertilisers[1]					
Moist conditions	83	79	41	75	20
Dry conditions	52	32	10	75	7
Significance[3]	**	**	**	n.s.	*
Superphosphate fertilisers[2]					
Moist conditions			77	94	69
Dry conditions			60	93	43
Significance[3]			**	n.s.	**

[1] DAP or MAP or NPK derived from these
[2] predominantly Superphosphate derived fertilisers
[3] Level of significance * 0.01 > p <0.05, ** p <0.01, n.s. not significant

Table 3. The effect of three moisture regimes on the germination of Swedes in the glasshouse.

Treatment	% Germination
Moist seed bed	90
Dry seed bed	28
Dry followed by moist conditions	65
$LSD_{5\%}$	20

Table 4. Germination and yield of bare turnip seed mixed with various fertilisers, (after Hayward and Scott 1993)

Treatments – applied at 20kgP/ha	Plants/m^2	Yield, tDM/ha
Control	26.1a	6.5ab
Lime Reverted Super (dry blend)	26.4a	10.0a
Longlife Super	28.0a	8.3ab
Super	26.2a	8.4ab
Nitrogen Super	18.6ab	8.2ab
MAP	20.7ab	8.0ab
DAP	22.5ab	8.6ab
Cropmaster 20	13.9b	4.1b

Significance, 5% level

Table 5. Main effects of placement of various fertilisers relative to seed on germination of peas, barley and wheat.

Crop	Treatments	Placement	Plant/m^2	Yield t/ha
Peas	Mean of 4 products, Pot.Super, DAP, MAP based fertilisers	Broadcast	93	6.32
		Drilled	86	6.17
Significance[1]			**	n.s.
Barley	Urea, mean of 4 rates 25-100kgN	Broadcast	146	5.56
		Drilled	94	4.62
Significance[1]			ŧ	n.s.
Wheat	Urea or ammonium sulphate, mean of 3 rates 40-80kgN drilled, 100-200kgN broadcast	Broadcast	248	
		Drilled	182	
Significance[1]			**	

[1] Significance 0.05 > ŧ <0.1, 0.01 > * < 0.01, ** < 0.01

Table 1. Composition and nutrient rating of fertiliser products discussed.

Product	Salt Index[1]	Nutrient Rating, % N	P	K	S	Description
Super	7.8	0	9	0	12	Superphosphate, approx 90% water soluble P (wsp)
Lime Reverted Super	7.0	0	7	0	9	Co-granulated or blended 75% Superphosphate, 25% Lime, variable wsp 30-60%
Longlife Super	6.0	0	10	0	8	Co-granulated 67% Superphosphate, 33% North Carolina Phosphate Rock, 45-50% wsp
Super/NC	4.0	0	11	0	6	Blend of 50% Superphosphate, 50% North Carolina Phosphate Rock, 45% wsp
15% Potassic Super	24.0	0	8	8	10	Blend of Superphosphate and Potassium Chloride
N Super	26.2	6	6	0	14	Blend of 70% Superphosphate, 30% Ammonium Sulphate
DAP	29.9	18	20	0	0	Di ammonium phosphate, 95% wsp
Cropmaster 15	58.9	15	10	10	8	Blend of 50% DAP, 30% Ammonium Sulphate, 20% Potassium Chloride
Cropmaster 20	49.5	20	10	0	12	Blend of 50% DAP, 50% Ammonium Sulphate
MAP	34.2	11	22	0	0	Mono ammonium phosphate, 85% wsp
Ammophos Hycrop Pea or 8-15-15	58.8	8	15	15	0	Blend of 70% MAP, 30% Potassium Chloride + Mo (Pea fertiliser)
Ammophos Hycrop 10	63.4	10	11	13	6	Blend of 50% MAP, 25% Ammonium Sulphate, 25% Potassium Chloride
Nitrophoska 12-10-10	56.0	12	10	10	1	Compound fertiliser, BASF Germany
Urea	75.4	46	0	0	0	
Ammonium Sulphate	69.0	21	0	0	24	
ASN	83.3	26	0	0	14	Ammonium Sulphate Nitrate, BASF Germany
FB48		--	--	--	--	Fertiliser Borate 48, Na borate 14%B

[1] Salt Index (estimated where raw material index known) indicates the likely osmotic pressure a fertiliser generates in solution as compared to the same weight of sodium nitrate – various sources