Comparing wood pulp and sawdust as media for field crops and the glasshouse

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Abstract

Partially composted kraft wood pulp and sawdust were trialled as media for establishing seeds in the glasshouse as well as for establishing and growing onions in the field in a system designed to give growers some control over the nutrient uptake of their crops. Wood pulp stored twice as much easily available water as a silt loam and sawdust, but only half as much as peat. Fast-growing seedlings (radishes) showed symptoms of nitrogen deficiency when grown in wood pulp, even with Nutricote® added at 2 g/L (5.7 mgN/plant).

Previously we used sawdust in a similar system to grow low sulphur (S) onions in the field on a moderately high S soil (Trolove and Reid, 2003). The wood pulp experiments showed that wood pulp contained too much plant-available S to be used in a system to reduce S uptake by plants; but in other respects it proved to be an effective medium, producing an onion crop with yield and composition of other nutrients similar to crops grown in sawdust. Sawdust contained low amounts of all plant nutrients, but had a poor water-holding capacity and was susceptible to being blown away by wind. Further research is needed to find a medium that would be suitable for use in the system designed to control the S uptake of a field-grown crop.

***Additional keywords*:** sulphur, onions, potting mix.

Introduction

In an earlier paper (Trolove and Reid, 2003), we described a system designed to give growers some control over the nutrient uptake of a field-grown crop. In brief, the system involved growing onions in 30 x 15 cm furrows filled with sawdust, and carefully controlling the amounts of nutrients supplied via trickle irrigation. Our hypothesis was that plant nutrients, such as N and S, would be immobilised to some extent as the sawdust decomposed, but the desired rate of nutrients could be supplied through drip tape running along the surface of the furrow. We also hypothesized that plant roots may be concentrated in the furrow where the nutrients were regularly supplied. To test our system, our objective was to grow low S onions on a moderately high S soil. Although initial results showed that two-thirds of the roots penetrated into the soil below the furrows, bulb tissue analysis showed that it was possible to produce low S onions on a high S soil using this system. Bulbs grown in the sawdust system contained 46% less S than onions grown in soil.

A problem associated with this system was the poor water-holding capacity of the sawdust medium. A large amount of water was applied in an effort to keep the sawdust moist enough to reduce the need for roots to grow into the soil in search of water. The total amount of water the plots received was 1.7 times the potential evapotranspiration (PET) for that period. As an undesirable consequence, the soil below the furrows became gleyed.

Therefore, it was important to look for a more suitable medium to fill the furrows. The medium would need to have a high ratio of carbon (C) relative to those nutrients that were present in undesirably high concentrations in the soil ('unwanted' nutrients) to ensure that the unwanted nutrients were immobilised as the medium decomposed. The medium should also be cheap, lightweight (to reduce transport costs and reduce soil compaction when the truck is driving over the field to apply the medium) and have a high water-holding capacity. Waste wood pulp generated by kraft mills meets the above criteria.

Ninety-five million tonnes of bleached kraft wood pulp are produced worldwide (Aracruz Cellulose, 2004). Kraft pulping is a low yield process, with only 45% of the wood being converted to pulp (Blum, 1996), so approximately 116 million tonnes of waste kraft pulp are produced worldwide each year. New Zealand has two kraft mills. In 2004 these produced 550,000 t of bleached and unbleached pulp and 320,000 t of kraft linerboards and semi chemical medium (Carter Holt Harvey, 2005), and so a large amount of waste wood pulp is also generated in New Zealand each year. Waste wood pulp is biodegradable and comes from a renewable resource. It appears to have good air and water-holding characteristics so may make a good medium for plant growth. However, it has a pH of approximately 8.0, which is much higher than that recommended by the Australian Standards® for potting mix of 5.3–6.5 (Standards Australia, 1996). Furthermore, it has a high sodium content (140 mg Na/L, *cf* the Australian Standards® recommendation of ≤60 mg Na/L for seedling mixes, or ≤130 mg Na/L for other mixes). Waste kraft pulp also contains a considerable amount of sulphide, which could (depending on the rate it is oxidised to plant-available sulphate) render the medium ineffective for controlling the S uptake of a crop.

The focus of this research was to compare the suitability of waste kraft wood pulp with the previously used medium (sawdust) for growing a crop in the field. A third treatment of 50:50 wood pulp and sawdust was included as this medium should have a lower pH and less sodium and S, but should have considerably better water-holding characteristics than sawdust. Transplanted onions were grown as the test crop, as in the previous experiment. An additional experiment was conducted to test the establishment of seeds in the media because transplanting is very costly, limiting the usefulness of the cropping system. When the field experiment showed that wood pulp had promise as a medium for seedling establishment, two additional experiments were performed to compare wood pulp with potting mix for the establishment of seedlings in the glasshouse.

Materials and methods

Laboratory experiment on water retention characteristics

Duplicate cores (56 mm diameter × 75 mm deep) were packed with composted wood pulp to a bulk density of 0.24 g/cm^3. Duplicate undisturbed cores of the same diameter were also taken from *Pinus radiata* D. Don sawdust that had been in furrows for 9 months. An additional undisturbed core of Mangateretere silt loam from the Crop & Food Research Station in Hawke's Bay, which had been cultivated 9 months previously, was also included for comparison. These cores were saturated with water for 4 days, their weights recorded, and then they were placed on a Haynes apparatus. A moisture retention curve was done for each core down to 100 cm of suction (De Boodt and Verdonck, 1972).

Field experiment 1. Comparing different media for growing onions: waste wood pulp, sawdust, a 50:50 mix of sawdust and wood pulp, and soil

Freshly milled, untreated *Pinus radiata* sawdust was obtained from the Whirinaki Mill in Hawke's Bay. Composted waste kraft wood-pulp was obtained from the Tasman Pulp and Paper Mill at Kawerau. These two wood wastes, plus a 50:50 mix (by volume) of wood pulp and sawdust, comprised the three growing media (treatments) tested in this experiment.

Soil preparation

A Mangateretere silt loam that had previously been in grass was ploughed then worked with a power harrow to a fine seedbed. Beds, consisting of four triangular furrows (30 cm wide by 15 cm deep), were made by dragging a heavy iron sled across the worked ground. Behind the sled was a tip trailer that filled the furrows with wood-waste media (sawdust, pulp or a 50:50 mix of sawdust + pulp). The shoulders of the furrows were covered to a depth of approximately 5 cm. Triple superphosphate, calcined magnesite and AgLime were broadcast over the surface of the wood waste at rates of 150 kg P, 330 kg Mg and 732 kg Ca per hectare (Table 1). No lime was applied to the pulp or pulp+sawdust treatments due to the high Ca content and pH of the wood pulp. Beds were 13 m long and 1.2 m wide. There was a 0.6 m space between each bed. There were 5 replicates of each treatment.

Table 1. Nutrients applied to the onion plots (kg ha^{-1}) for field experiment 1.

Source	N	P	K	S	Ca	Mg	Fe	Mn	Cu	Zn	B	Mo
Nutrient solution												
NH_4NO_3	110											
KNO_3	17		47									
KCl			47									
FeEDTA							2.3					
$MnSO_4$				0.11				0.18				
H_3BO_3											0.19	
$ZnSO_4$				0.009						0.021		
$CuSO_4$				0.003					0.005			
Na_2MoO_4												0.005
Solid fertiliser												
Ammonium nitrate	25											
Triple superphosphate		150		7								
Lime					732[1]							
Calcined magnesite						330						
Irrigation water	0.2		3	6	35	6	0.4		0.101		0.60	
Total	152	150	97	13	767	336	2.7	0.18	0.106	0.021	0.79	0.005

[1] Note that no lime was applied to the pulp or sawdust + pulp treatments

Fertigation system

One drip tape, with 0.98 L/hr emitters spaced 10 cm apart, was laid on the sawdust/pulp surface down the centre of each furrow. Nutrient solution (Table 1) was supplied daily through the drip tape at a rate to supply 1.5 kg N/ha/day. Plots were not fertigated on wet days so compensatory nutrients were applied on the next fine day.

Planting

Hybrid onion (*Allium cepa* L. cv. Kojak) seed was sown into transplanting trays on 23 and 27 August 2002. Onions were chosen as the test crop because they were used in the experiment the previous year, have a simple root system, and show a broad range in bulb S content, depending on the amount supplied. Seedlings were raised under plastic and transplanted in their plug of potting mix on 4 November at the 2 true leaf stage. The onions were transplanted in double rows within each furrow, with 6 cm between double rows and 10 cm between plants within a row. This gave a planting density of 67 onions/m^2 within the bed. All plots were watered by overhead sprinkler for two days following transplanting.

Water was applied daily (apart from rainy days). Soil moisture content was monitored twice weekly by time domain reflectometry using waveguides inserted through the soil ridges to 50 cm depth. Measured soil water content was maintained close to field capacity (36% volumetric) for the first 7 weeks of growth while the plants were established, then allowed to dry down to 27% where it stabilised for the remaining 5 weeks. This change was intended to lessen the risk of reducing conditions (gleying) developing in the soil, which was observed in the sawdust treatments of the previous season's trial.

Pest and disease control

Common sprays were used to control broadleaf weeds, onion thrips (*Thrips tabaci* (Lindeman)) and downy mildew (*Peronospora destructor* (Berk.) Casp. in Berk.).

Harvest

Onions were harvested on 12 March 2003 when 94% tops had fallen down. A 2 m length of bed was harvested. Subsamples were taken for shoot DW (75ºC) and the bulbs were cured outdoors in mesh bags for 16 days; fresh weight and bulb diameter were then recorded. A subsample of 20 onions were then quartered, dried at 75ºC and total N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, and Bo were determined.

Field experiment 2. Seedling emergence in different media

Furrows were formed as described above, then filled with either: waste wood pulp, *Pinus radiata* sawdust, a 50:50 sawdust:wood-pulp mix, or finely cultivated soil (Mangateretere Silt Loam). Plots, 1.5 m long, contained four furrows and were arranged in a completely randomised block design with five replicates. Coated onion (*Allium cepa* cv. Kojak) seed was sown on 19 November 2002 in a double row down the centre of each furrow at a spacing of one seed every 35 mm, giving a sowing rate of 228 seeds per metre of bed. The high sowing rate provided a large number of seedlings for emergence counts in the small plots, reducing the variability in the data.

Seeds were sown using a Stanhay drill. The sowing depth was highly variable due to the very soft nature of the substrate.

The sowing depth ranged from *c.*3 to 30 mm in the sawdust and pulp treatments. The plots were lightly raked (roughly equivalent to dragging a very light bar behind the drill) to cover over the trenches. Plots were fertigated with drip tape as described in the previous experiment. Emergence counts were taken 9, 17, and 27 days after sowing.

Seedling emergence data were also recorded for a similar experiment sown in 2003. Furrows were prepared and filled with sawdust as described above. A soil treatment was included as a control, and there were 4 replicates of each treatment. Composted kraft wood pulp was not used in this experiment because the 2002 experiment found it contained a large amount of plant-available S. coated onion (*Allium cepa* L. cv. Thunder (previously named Kojak)) seed was sown in double rows 60 mm apart, with 50 mm between each seed within the row, using the Stanhay drill described above. The onions were sown on 1 October 2003 and then, due to poor seedling establishment, the trial was sprayed off (with glyphosate) and resown on 30 October 2003. The seeds were fertigated through drip tape, as described for the other field experiments, at approximately two-thirds of the potential evapotranspiration (*c.* 3.5 mm of water per day on a sunny day).

Investigation of waste wood pulp as a seed-raising mix

Given the good water-holding properties of wood pulp, and the fact that onion emergence in the wood pulp was as good as in soil or sawdust, we examined the suitability of waste kraft wood pulp as a seed-raising mix. The four treatments are listed below:

Treatment name	Description
Pulp	unamended wood pulp
Pulp+Fert	fertilised wood pulp {Nutricote®[1,2] slow release fertiliser (N:P:K 15.2:4.7:8.9) at 2 g/L of media and H_3PO_4 at 86 mg/L of media}.
P+B+Fert	wood pulp mixed with bark at a 50:50 ratio (by volume) plus fertiliser added at the same rate as the Pulp+Fert treatment.
Potting Mix	Basics®[2,3] potting mix, which is a mixture of peat moss, finely milled bark and pumice plus added nutrients. This was used as a control.

[1] Yates New Zealand Ltd, 4 Henderson Pl, Onehunga, Auckland, NZ.
[2] Note that the mention of a product name does not constitute a recommendation of that product.
[3] General Distributors Ltd, 80 Favona Rd, Mangere, Auckland, NZ.

Radish (*Brassica sativus* L. cv. Champion) seeds were sown into seedling trays (with 19 mL cells) on 31 July 2003 and raised in a plastic house. The experiment was arranged in a completely randomised design, with one row of 20 cells comprising one 'plot'. There were 6 replicates per treatment. The outside rows of the trays were used as guard rows.

Emergence counts were taken at 2, 4 and 6 days after sowing. Seedlings were harvested when the largest plants had reached the two true leaf stage. The number of plants present per row and the dry weight (70 °C) of the row of seedlings were recorded.

A second experiment compared the seedling emergence of two annual flower species: pansy (*Viola wittrockiana* cv. Joker Mixed) and snap dragon (*Antirrhinum majus* cv. Chimes Mixed) in the wood pulp, bark and fertiliser mix (P+B+Fert described above) with emergence in Basics® potting mix. These two flower species were selected because they are more difficult to germinate than most commonly grown commercial plants. The experiment was a completely randomised design, with one row of twenty 19 mL cells comprising one 'plot'. There were 7 replicates per treatment. The outside rows of the trays were used as guard rows.

Statistics

Data were analysed using GenStat. T-tests were conducted to determine the significance of differences in chemical properties of the media between the start and end of the experiment. The remaining data were analysed by ANOVA. Separate ANOVAs were conducted for each date for the onion emergence trial.. Where percentages were <20%, such as early emergence percentages, the data were angular transformed prior to ANOVA. Differences are reported as being significant at $P<0.05$ unless otherwise stated.

Results and Discussion

Laboratory experiment on water retention characteristics

De Boodt and Verdonck (1972) defined the easily [plant-] available water (EAW) in a substrate as "the quantity of water released from the material studied when the suction increases from 10 to 50 cm". Further, they labelled the water stored between 50 and 100 cm of suction as the "water buffering capacity" (WBC). According to De Boodt and Verdonck (1972), an ideal substrate should have a total pore space of 85%, air-filled porosity of 20-30%, EAW of 20-30% and a water buffering capacity of 4– 10%. Wood pulp stored twice as much (EAW) as the Mangateretere silt loam or sawdust and had a six-fold greater water buffering capacity (WBC) than sawdust (Table 2). However, wood pulp does not store as much EAW as peat (Goh and Haynes, 1977), although it had a higher WBC. Wood pulp did not have an EAW of between 20 and 30% as recommended by De Boodt and Verdonck (1972) for ideal substrates, but was certainly superior to soil or sawdust, and warrants investigation for use as a potting mix or for inclusion as part of a potting mix, particularly since it is a renewable resource whereas peat is non-renewable.

The sawdust stored a similar amount of EAW to the soil (Table 2). This is much greater than the value of 3.8% measured by Goh and Haynes (1977). However, Goh and Haynes probably used fresh sawdust, whereas this sawdust had been weathering outside for 9 months. Presumably the water-holding capacity of the sawdust increases as the sawdust decomposes and particle size diminishes.

Field experiment 1.
Comparing different media for growing onions: waste wood pulp, sawdust, a 50:50 mix of sawdust and wood pulp, and soil.

Chemical properties of the wood media at the start and end of the experiment

The concentrations of most nutrients increased over time as a result of adding fertiliser (Table 3). There was a large increase in CEC for the sawdust as it decomposed. This enabled the sawdust to hold considerably more nutrients, and the amount of cations held by the sawdust increased accordingly. In contrast, the CEC of the partially decomposed wood pulp declined by 22%. This resulted in a decline in the amount of exchangeable Ca and Na held, while the amounts of Mg and K increased.

The C content of the fresh sawdust decreased with time as it decomposed, but there was no change in the C content of the partially decomposed wood pulp. SO_4-S was not applied as a fertiliser and, in the sawdust treatment, showed little change over the growing season. This suggests that the SO_4-S taken up by the onions (27 kgS/ha) was mostly supplied by mineralisation from the soil. The SO_4-S concentration in the wood pulp declined by a

Table 2. Water retention properties for different media.

Medium	Bulk density	Total pore space	Air space	Easily-available water	Water buffer capacity
	(g/cm^3)	(% of volume)			
Soil	1.12	56.8	9.7	7.5	2.8
Sawdust	0.14	74.5	38.4	7.2	1.4
Sawdust[1]	0.14	71.6	42.3	3.8	1.9
Wood pulp	0.24	88.1	18.0	15.3	8.3
Dipton peat[1]	0.22	89.5	19.8	34.2	3.1

[1] From Goh and Haynes (1977)

factor of 7 over the growing season. This is likely to be largely due to plant uptake. Total S uptake by the onion crop grown in the wood pulp was 41 kgS/ha (for bulb yield and nutrient content, see Table 4). The total drop in SO_4-S content in the wood pulp equated to 9 kgS/ha, based on a bulk density for the medium of 0.28 Mg/m^3. The remaining 32 kgS/ha would have come from mineralisation of S from the wood pulp, and from the soil.

Yield

There was no significant difference in onion bulb fresh weight between the sawdust or pulp treatments (Table 4). The 50:50 mix of wood pulp and sawdust yielded significantly less than the other two treatments. This lower yield is difficult to explain; three replicates of the 50:50 mix treatments were planted at a slightly lower density than the other media, yet the low yields were not necessarily found in those treatments with a low plant density. Plant density was not significant (P=0.73) when used as a covariate to explain differences in yield.

Table 3. Important chemical characteristics of the wood wastes at the start and end of field experiment 1. The soil samples were taken from the ridges between the furrows and averaged across all 15 plots.

	pH	Bulk density	Olsen P	CEC	Ca	Mg	K	Na	Total C (Leco C)	Mineralisable N	SO_4-S
		(Mg/m^3)	mgP/L	meq/100 g					%	(kgN/ha)	(mgS/kg)
Sawdust - start	5.8	-	6	9	5	1.3	1.8	1.0	49.0	0	16
Sawdust - end	6.3	0.14	117	94	58	22.5	7.2	2.9	41.3	95	13
Significance‡	(*)		***	***	***	***	***	**	(*)	***	ns
Pulp – start	7.9	-	6	93	88	1.7	0.5	2.1	21.3	38	48
Pulp – end	7.3	0.28	127	73	64	6.6	1.3	0.9	22.3	265	7
Significance‡	***		***	*	**	**	***	**	ns	***	***

‡ Significant by paired t-test. (*) P<0.1, * P<0.05, ** P<0.01, *** P<0.001

Table 4. Establishment, yield (fresh weight) and bulb nutrient content of transplanted onions grown in different wood-waste media in field experiment 1. Data are means of 5 replicates and the SE Mean is in parenthesis.

Medium	Establishment	Yield	N	P	K	S
	(plants/m^2 bed)	(tFW/ha)	%			
Pulp	65.4 (0.4)	66.8 (1.0)	1.36 (0.05)	0.27 (0.004)	1.22 (0.04)	0.31 (0.01)
Pulp+Sawdust	60.1 (2.5)	61.2 (2.6)	1.30 (0.04)	0.27 (0.008)	1.20 (0.03)	0.27 (0.02)
Sawdust	63.3 (1.0)	66.4 (1.5)	1.33 (0.08)	0.27 (0.013)	1.24 (0.02)	0.19 (0.01)
Significance	ns	0.04	ns	ns	ns	0.03
LSD (5%)	5.6	4.7	0.12	0.04	0.24	0.07

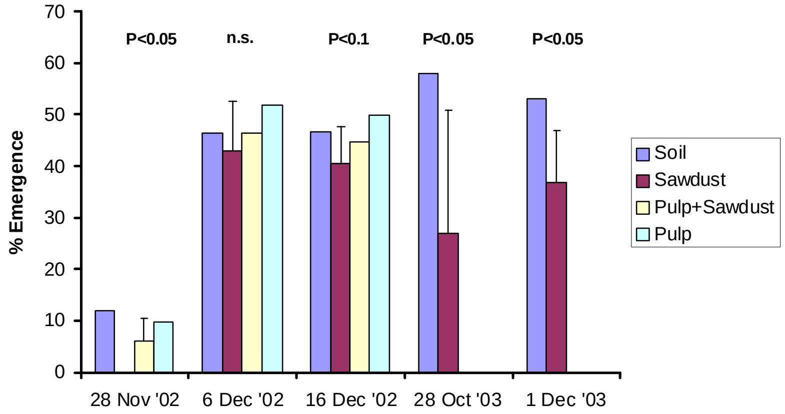

Figure 1 Emergence of onions grown in different media. Results are given for three dates in 2002 (field experiment 2) and one date each for two different sowings in a 2003 experiment. Bars denote LSD (5%) for comparing treatments at each sampling date. Note that on 28 November 2002 only 1 seedling had emerged in the sawdust treatment out of all 5 plots (seedling emergence <0.1%) so this treatment was excluded from the ANOVA.

There was no significant difference in bulb N, P and K content (Table 4). This was expected since all treatments received the same amounts of these nutrients. Onions grown in wood pulp and the 50:50 wood pulp:sawdust mix contained significantly more S than onions grown in sawdust. This shows the S in wood pulp is plant-available.

Field experiment 2. Seedling emergence in different media

Onion seeds emerged significantly slower in the sawdust (Figure 1). Presumably this was due to the lighter colour of the sawdust, which would have meant that the temperature around the seed was slightly cooler than the darker coloured soil and wood pulp. The emergence rate of onions grown in the 50:50 sawdust:wood-pulp mix (and the colour of the media) was intermediate between the wood-pulp and sawdust. Eight days later there was no significant difference in emergence between any of the treatments. Waiting a further 10 days gave no further improvement in seedling germination.

In 2003, however, onion emergence in the sawdust was half to two-thirds the value ($P<0.05$) of that obtained in soil. A possible reason for the differences between the 2002 and 2003 sowings may be the wind. The differences did not appear to be related to temperature or rainfall. (For the week prior to the emergence counts, average daily maximum temperatures and rainfall were 22, 16 and 18 °C, and 2, 2 and 59 mm, for the 6 December 2002, October 2003 and November 2003 sowings, respectively). The maximum daily wind run between 29 November 2002 and 6 December was 267 km/day. However, the daily wind run for 3 days prior to the October 2003 observations was between 400 and 445 km/day (the 30-year average wind run for October is 245 km/day). Soon after emergence these strong winds blew the light, dry sawdust particles into the young onions, damaging the young hypocotyl. Once damaged, the hypocotyl quickly desiccated and the young seedling either died or became desiccated down to ground level. These winds were the reason for resowing the trial, generating the December data. The maximum daily wind run recorded during the period of emergence for the second sowing in 2003 (some data were lost due to equipment failure) was 367 km/day. The sawdust does not blow readily when wet. However, sawdust is poor at conducting water laterally, and so the sawdust on either side of the drip tape remained dry. The sawdust system therefore requires another means of watering the furrows for seedling establishment in dry, windy conditions or, preferably, another medium that does not blow away and has better water-supplying characteristics.

The emergence percentages were low in all treatments, suggesting that none of the treatments provided ideal conditions for seed germination.

Investigation of waste wood pulp as a seed-raising mix

For all three plant species tested there was no significant difference in emergence among the wood-pulp-based media and the potting mix (Table 5). Radish emergence was high in all media (≥97%) with little variation among replicates, as indicated by the low LSD. In contrast, emergence of the flower seedlings was poor (<50%) and highly variable, which is again indicated by the high LSD for these treatments.

There was a large and highly significant difference in plant size (Table 5). Radishes were much larger in the potting mix than in the wood-pulp-based media. This appeared to be due to N deficiency in radishes grown in the wood-pulp-based media; these radishes were very pale green to yellow whereas those in the potting mix were a much darker green. Visually, the pansies and snapdragons showed no size or colour differences (no data collected) between those grown in wood pulp and those grown in potting mix. The two flower species grew much slower than radish and therefore wood pulp must have supplied N at a rate that was adequate for their growth, unlike radish.

Table 5. Seedling radish dry weight, and establishment for three different plant species, grown in different seed raising media.

Medium	Radish dry weight (g)	Radish establishment	Pansy establishment	Snapdragon establishment
		(plants/20 cells)		
Potting mix	2.74	19.8	6.4	8.9
Wood pulp	0.82	19.3	6.4	9.4
Pulp+Fert.	0.80	19.3		
Pulp+Bark+Fert.	0.76	19.3		
Significance	<0.001	ns	ns	ns
LSD(5%)	0.070	0.7	5.6	8.1

The suitability of wood-waste media for growing a crop in the field

Wood pulp has good aeration, a high plant-available water holding capacity and CEC, is lightweight and a dark colour, which are all good properties for a plant growth medium. Wood pulp also does not blow away in the wind, unlike sawdust. It has a high C:N ratio and immobilised N, making it suitable in a growing system where soils were high in N and it was necessary to reduce plant N uptake. However, wood pulp contains a large amount of plant-available S so was not suitable in a system for controlling the S uptake of plants. The high concentrations of Na did not appear to reduce the germination of onions, radish, snapdragon or pansy, and the decline in Na concentrations in the wood pulp during the growing season suggested

Sawdust holds much less water than wood pulp and is more susceptible to being blown away by wind. The nutrient-holding capacity of sawdust increases dramatically as it decomposes, and it appears that the water-holding capacity of the sawdust also increases (if we assume that Goh and Haynes (1977) used fresh sawdust). Therefore, if sawdust is to be used as a growing medium it should be composted first.

Conclusions

Partially decomposed waste kraft wood-pulp had good physical properties as a plant growth medium, although it did not hold as much water as peat. It is lightweight, holds a large amount of air and plant-available water, and is a dark colour. It requires the addition of readily-available N to be a suitable medium for plant growth. Waste wood-pulp contains too much plant-available S to be used in a system to reduce S uptake by plants. Sawdust contains low amounts of all plant nutrients, but has a poor nutrient and water-holding capacity and is susceptible to being blown away by wind. Further research is needed to find a medium that would be suitable for use in a system designed to control the S uptake of a field-grown crop.

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