Identifying the mechanisms controlling crop response to subsoil amelioration with nutrient enriched organic matter

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Abstract
Deep placement of nutrient enriched organic matter (NEOM) may ameliorate subsoil constraints and improve crop productivity. The mechanism(s) responsible is unclear, e.g. improved nutrient supply, improved soil structure, reduced toxicity or some combination of these. Two glasshouse experiments using PVC columns containing a sodic subsoil were undertaken. The effect of NEOM application on wheat growth was compared with treatments designed to increase soil carbon (C) in the presence/absence of added nutrients (+NPKS), improved soil structure (polyacrylamide soil conditioner), tolerance to high sodium (using tolerant lines) or a combination. Biomass production resulting from NEOM application (48.4 g/core) did not differ from +NPKS (49.7 g/core) or +NPKS & Model C (49.5 g/core). NEOM application did not increase grain yield in the presence of +NPKS and/or PAM treatments; 55.8 versus 55.4g/core for +NPKS & PAM with and without NEOM, respectively. NEOM can increase biomass and grain yield, with results suggesting the likely mechanism is not limited to improved nutrition alone, but also potentially due to improved soil structure.

Keywords
Nutrients, PAM, gypsum, subsoil constraints, soil structure

Introduction
Application organic matter to the subsoil can help to improve grain yields and ameliorate subsoil constraints. Several mechanisms have been proposed by which organic matter may help to achieve this. These include directly enhancing nutrient supply (Celestina et al. 2019), improvement of soil structure (which would facilitate root access to water and nutrients), or alleviation of toxicities (Fageria 2012). There is, however, debate as to which of these mechanisms is controlling crop responses observed (Sale et al. 2019), making it difficult to predict where amelioration will be effective. To better understand the mechanisms controlling crop response to subsoil amelioration, we undertook two glasshouse experiments. The first focussed on the improved nutrition and the second integrated the use of chemical, physical and genetic (tolerance) amelioration strategies in an effort to discern which factor was controlling the crop response to organic matter.

Methods
Two glasshouse experiments were conducted. Experiment 1 (Nutritional effects) used a sodic soil and was comprised of 5 nutrient treatments (Control, +NPKS, +NPKS & Model C, +Model C source and NEOM) by 4 replicates. The model C source was comprised of D-Glucose, Mannose, Cellulose and Guaiacol. The NEOM (chicken manure) was applied at 20t/ha equivalent; typical of field applications. Nutrients were applied as urea, triple super and potassium sulphate and calcium nitrate, at rates equivalent to that applied in the NEOM (663 kg N/ha, 400 kg P/ha, 540 kg K/ha and 136 kg S/ha).

Experiment 2 (Mechanisms) was a factorial with two soils (sodic and non-sodic soil) and six mechanistic treatments: plus or minus NEOM. The treatments consisted of a control (no ameliorant), +NPKS (applied as per experiment 1), polyacrylamide (PAM @ 5t/ha), gypsum (@ 5t/ha, sodium tolerant Westonia-Nax 1 and + NPKS & PAM. Treatments were replicated 4 times.

Reconstituted soil cores (60 cm long x 15 cm diameter) were used. The nutrient enriched OM was mixed as a 4 cm diameter x 20 cm long ‘sausage’ placed longitudinally in the centre of the core at 20-

40 cm depth. The PAM and gypsum were mixed throughout the 20-40 cm layer. A 10 cm layer of intermediate subsoil and 10 cm of topsoil, containing basal nutrients (N, P, K, Mg, Cu and Zn) were placed on top of the amended subsoil. Soils are described in Table 1. Cores were constructed using air-dry soil and were gradually wet up to 70% PAWC using the subsoil irrigation and surface watering. Overall, wetting up took approximately 2 months. During the experiment the cores were watered from the top only, with small amounts (up to 240 ml) of water applied on an almost daily basis, in an effort to increase soil moisture to 95% PAWC. The plants rapidly used this water so the desired increase was not achieved. Watering ceased one month before harvest (GS92). The experiments were run simultaneously in a naturally lit glasshouse in Horsham, Victoria. Temperatures were set to a maximum of 18 ºC during the day and 12 ºC at night, although daily maximums exceeding 25 ºC were observed. All cores were sown with 6 seeds of wheat cv. Westonia, except for the Westonia Nax 1 treatment (Na+ tolerant line) on the 23rd August 2019. Seedlings were thinned to 3 plants per core at two leaf stage. At GS92, plants were harvested, oven dried at 70 ºC before determining shoot biomass and grain yield. Soil collected from the amended layers at harvest, underwent turbidity analysis which involved slowly inverting 1 g of soil (<2mm) plus 25ml RO water. 20 times before leaving it to settle and then reading on a Hach TL23 Turbidimeter. Data were analysed using ANOVA (Genstat v18). Analysis from Experiment 2 showed some effects of soil type, but the 3-way interaction was not significant.

Table 1. Physicochemical properties the soils used in Experiment 1 and 2

	Soil	pH ($CaCl_2$)	EC (dS/m)	ESP	B (mg/kg)	Organic C (%)	Total N (%)	LSL (%)	FC (%)
All	WRS Topsoil	7.7	0.27	4.1	2.1	1.5	0.13	20	54
Benign	WRS Subsoil	7.9	0.16	1.4	2.7	0.8	0.08	20	50
Hostile	PBC intermediate	8.2	1.92	16.0	20	0.2	<0.05	23	47
Hostile	Clear Lake subsoil	6.9	0.33	35.6	5.7	0.6	0.08	28	65

Results

Experiment 1- Nutritional effects

Shoot and root biomass at grain maturity was highest in the +NPKS, +NPKS & Model C and NEOM treatments (P <0.001 and P = 0.001) (Table 2). The NEOM and +NPKS treatments also produced the highest grain yields (P = 0.001). The +NPKS & Model C treatment however produced significantly less grain yield compared to the NEOM treatment. The +Model C treatment produced the least biomass and smallest yield and was not significantly different to the Control. In contrast, harvest index values were highest for the Control and NEOM treatment, followed by the +Model C (P <0.001) and were lowest for the +NPKS & Model C (Table 2). Nutrient treatment had no significant effect on 1000 grain weight (P = 0.207) (Table 2). Grains per core was highest in the NEOM, +NPKS and +NPKS & Model C treatments (P = 0.009) (Table 2). Given the trends in biomass, grain yield components observed in this experiment, it is likely differences in the amount and pattern of water use by the crop are responsible for these results. Shoot uptake of N, P K and S confirmed higher levels of nutrients in the +NPKS and +NPKS & Model C treatments, followed by the NEOM treatment (P <0.001 for all) (data not presented). These results suggested the wheat was benefiting from improved nutrition as a result of the NEOM addition. Grain protein was high (>15%) in the +NPKS and +NPKS & Model C treatment, intermediate (10.3) in the NEOM treatment and low for the +Model C (8.3) and Control (8.7) (P <0.001) (data not presented). The lower levels of nutrients and grain protein in the NEOM treatment, compared to the +NPKS treatments would be due to a slower release of nutrients, compared to the readily available nature of the fertilisers used. Differences in grain yield between the NEOM and +NPKS & Model C treatment appears to be the result of a lower number of grains being set in the +NPKS & Model C treatment. An explanation for the lower grain set however is unclear and does not appear to be explained by differences in nutritional supply.

Table 2. Shoot biomass, root biomass, grain yield and yield components of wheat grown in the presence of five different nutrient treatments

Treatment	Shoot biomass (g/core)		Root biomass (g/core)		Grain yield (g/core)		1000 grain weight (g)	Harvest index		Grain No. (grains/ core)	
Control	40.9	b	1.8	bc	17.9	bc	42.3	0.44	a	423	ab
+ Model C	36.7	b	1.6	c	15.4	c	43.6	0.42	a	353	b
+NPKS	49.7	a	2.3	a	19.6	ab	38.1	0.39	b	517	a
+NPKS & Model C	49.5	a	2.1	ab	17.9	bc	39.9	0.36	c	469	a
NEOM[1]	48.4	a	2.5	a	21.4	a	41.4	0.44	a	518	a
P value	<0.001		0.001		0.001		0.207	<0.001		0.009	

[1] nutrient enriched organic matter

Experiment 2- Mechanisms

Treatments containing nutrients and/or PAM produced the most biomass ($P < 0.001$). Addition of NEOM lead to a significant increase in shoot biomass and grain yield in the Control, Westonia Nax-1 and Gypsum treatments only; NEOM had no significant effect in the nutrient and/or PAM treatments ($P < 0.001$ and $P = 0.003$) (Table 3). Overall, shoot biomass was significantly higher where NEOM was added (54.0 vs 50.5g/core, $P < 0.001$). NEOM had no significant effect in the WRS soil, but increased biomass on the hostile Clear Lake soil ($P = 0.01$) (data not presented). Harvest index was significantly lower in the +NPKS and +NPKS & PAM treatments ($P < 0.001$), compared to the Control, Westonia Nax-1, Gypsum and PAM treatments (Table 3). Thousand grain weights were highest for the +NPKS and Westonia Nax-1 treatment, followed by the Control and Gypsum (Table 3) ($P < 0.001$). The smallest grain weights were observed for the PAM and +NPKS & PAM treatments. The number of grains per core was higher where NEOM was added ($P = 0.01$) (Table 3) and in the Clear Lake soil ($P = 0.02$). The PAM and +NPKS & PAM treatments produced more grains than the other treatments ($P < 0.001$). Again, it is likely that some of these results are related to differences in the pattern and volume of crop water use.

Table 3. Shoot biomass, grain yield of wheat grown in the presence of different treatments and in the presence or absence of added NEOM

Treatment	NEOM	Biomass (g/core)		Grain yield (g/core)		Harvest index		1000 grain weight (g)		No. grains per core	
Control	Minus	45.0	d	18.0	cd	0.39	a	41.2	b	473	b
	Plus	53.4	bc	20.9	ab						
Westonia Nax-1	Minus	47.6	d	17.8	cd	0.38	a	41.6	a	464	b
	Plus	54.3	abc	20.7	ab						
Gypsum	Minus	44.7	d	17.3	d	0.39	a	41.2	b	456	b
	Plus	51.4	c	20.4	ab						
PAM	Minus	53.8	abc	21.1	a	0.38	a	37.3	c	555	a
	Plus	54.6	abc	20.0	abc						
+NPKS	Minus	56.7	a	19.4	abcd	0.33	b	42.3	a	454	b
	Plus	54.8	ab	18.1	cd						
+NPKS & PAM	Minus	55.4	ab	19.6	abc	0.34	b	37.1	c	532	a
	Plus	55.8	ab	18.6	bcd						
P value		<0.001		0.003		<0.001		<0.001		<0.001	

Aggregate stability was affected by a 3-way interaction between soil, NEOM and treatment (*P* <0.001) (Figure 1). For the Clear lake soil aggregate stability was improved by any treatment, other than the Westonia Nax-1. Addition of the NEOM resulted in significant reductions in turbidity for the +NPKS and Gypsum treatments. Aggregate stability for the PAM and +NPKS & PAM treatments did not show further improvements from the NEOM application. Results from the WRS soil showed an increase in aggregate stability from addition of PAM, but NEOM addition had no effect.

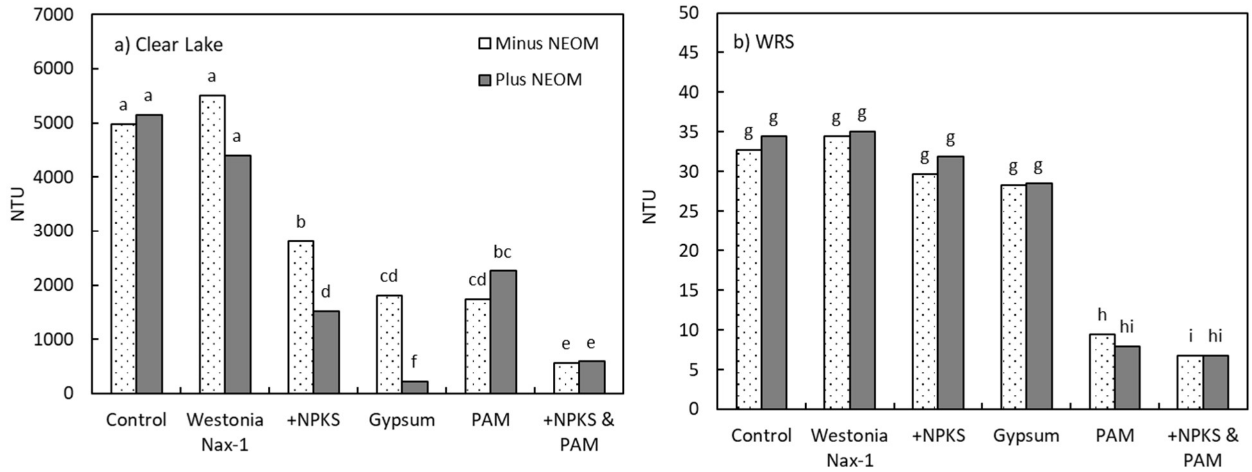

Figure 1. Nephelometric turbidity units (NTU) for a) Clear Lake and b) WRS soil collected from the amended layer of the core, post-harvest

Conclusion

The results of these experiments suggest that NEOM does provide improved nutrition to wheat, similar to that of applying equivalent rates of inorganic NPKS fertilizer, as evident through the production of similar biomass and grain yields. The results of the second experiment, however, suggest the mechanism is not limited to improved nutrition alone, but also potentially due to improved soil structure as evident through the PAM treatment. It is likely that differences in the amount or pattern of water use affected the biomass production and grain yield of the treatments, particularly the nutrient treatments. Further experimentation, paying close consideration to differences in seasonal and spatial distribution of soil water would enhance our understanding of these mechanisms. Furthermore, these experiments were conducted over one cropping cycle; there is the potential for greater or different crop responses to the various mechanism treatments in further cropping cycles (S Uddin and M Weiss pers. comm 2021).

Acknowledgements

This research was co-funded by the GRDC and Agriculture Victoria (Project DAV00149).

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