Physical properties of organo-mineral fertilizers – Short Communication

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Paré, M.C., S.E. Allaire, L. Khiari and C. Nduwamungu. 2009. **Physical properties of organo-mineral fertilizers – Short Communication.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **51**: 3.21–3.27. The physical properties of organo-mineral fertilizers (OMF) are poorly understood, but must be measured because they affect OMF transport, storage, handling, and soil behaviour. The aim of this study was to determine the relationships among physico-chemical properties so that the number of measurements required by the industry during manufacturing is reduced. Organo-mineral fertilizers were granulated into 50 mixtures of composts, peat, and mineral fertilizers. Fifteen physical properties and 12 chemical properties were measured following standard and modified methods. Bulk density, easy and inexpensive to measure, significantly affected other physical properties ($R^2 > 0.74$), such as tapped and granule densities and porosities, and crushing strength. In addition, concentrations of Fe, Mg, organic matter, and Na significantly affected many physical properties of OMF granules, whereas other chemical properties had a limited effect. These findings will directly affect OMF manufacturing by reducing time and costs needed for property measurements related to product development and quality control. **Keywords:** organic fertilizer, pig slurry, fertilizer manufacturing, granule.

Les propriétés physiques des engrais organo-minéraux (EOM) sont très peu connues, mais sont d'une grande importance puisqu'elles affectent le transport, l'entreposage, la manutention et la dynamique de ces engrais une fois appliqués au sol. L'objectif de cette étude était de définir les relations entre les propriétés physico-chimiques des EOM afin de réduire le nombre de propriétés qui doivent être mesurées par l'insdutrie pour le développement de nouveaux produits et le contrôle de la qualité. Cinquante mélanges de composts, tourbe et engrais minéraux ont été granulés en EOM. Quinze propriétés physiques et douze propriétés chimiques ont été mesurées utilisant des méthodes standards et modifiées. La masse volumique apparente – une mesure rapide et peu coûteuse – influençait d'autres propriétés physiques ($R^2 > 0.74$) relatives à la densité, la porosité et à la résistance à l'écrasement. Par ailleurs, quelques propriétés chimiques telles que les concentrations en Fe, Mg, matières organiques et Na influençaient plusieurs propriétés physiques des granules d'EOM. Les autres propriétés physico-chimiques étaient peu corrélées avec les propriétés des physiques des granules. Cette étude permettera de réduire les coûts reliés aux mesures physico-chimiques faites sur les EOM pour le contrôle de qualité et le développement de nouveaux produits. **Mots clés:** engrais organique, lisier de porc, fabrication d'engrais, granule.

INTRODUCTION

Organo-mineral fertilizers (OMF) offer several advantages over organic amendments or mineral fertilizers. They improve plant-mineral interaction by reducing mineral sorption of phosphorus (Chaabane 1994; Parent et al. 2003), decreasing the transformation of P_2O_5 into plant unavailable forms (Iyamuremye et al. 1996; Khiari and Parent 2005), activating young plant rooting activity (Lee and Bartlett 1976), and affecting oxydo-reduction in soil (Tishkovitch et al. 1983). Organo-mineral fertilizer usage is expected to increase in the near future. Therefore, a better understanding of the physical properties related to their storage, handling, and soil behaviour is needed.

Many physical properties of granular fertilizers are measured by industry, including particle size distribution (Hoffmeister 1982), fertilizer dissolution (Polyankov et al. 1985), bulk density (Raviv et al. 1987), and field spreading homogeneity (Hoffmeister 1979). In addition, granules must have sufficient mechanical strength to withstand normal handling and storage without significant fracturing and creation of excessive dust (Hoffmeister 1982). High crushing strength and abrasion resistance are required to prevent formation of fine particles and caking problems (Hofstee and Huisman 1990). Density properties are used to calculate the volume necessary to store, transport, handle (Agnew and Leonard 2003), and calibrate fertilizer field applicators (Hoffmeister 1979). Water sorption affects nutrient dissolution rate (Allaire and Parent 2004a) and granule crusting (i.e., packaging requirements). Fertilizers with low water sorption from the atmosphere (WSA) can tolerate humid air without caking and sticking on field equipment (Hoffmeister 1982; Jumpei et al. 1965). Water sorption from the soil by the fertilizer granules is also important as the granule water content determines the rate of slaking and chemical diffusion.

Physical properties of OMF have rarely been reported except in a few studies (Allaire and Parent 2003, 2004a, 2004b; Bovolenta and Pezzi 1996). In addition, it might be unrealistic for the industry to measure all relevant physical properties for quality control as well as product development. The objectives of this study were to determine (1) the relationships between physical and chemical properties of OMF granules and (2) the most relevant OMF properties to be measured in order to reduce the number of measurements necessary to characterise physical properties of OMF granules.

MATERIALS and METHODS

Granulation

Fifty mixtures of four different composts, monoammonium phosphate (MAP), diammonium phosphate (DAP) (SynAgri Inc., Québec, Canada), and peat (Premier Horticulture ltée, Rivière-du-Loup, Canada) were completed at different ratios. Composts were made from stabilized dry pig slurry obtained from several separation techniques and mixed with other organic materials (Table 1). Composts and peat were air-dried and sieved using 2.3 and 0.75 mm sieves, respectively. The mixtures were granulated using a small commercial radial extrusion granulator (model 4822, Hobart, Paris, France) and water was added to reach sufficient cohesion. Granules were then dried at 70°C for 18 h and stored in plastic containers at room temperature. Three replicates were completed for each treatment (i.e., mixtures).

Physical properties

Particle size distribution was measured using a mechanical sieving technique. Fifty grams of granules were placed on 8, 4, 3.35, 2, 1, 0.5, and 0.25 mm sieves and shaken for 5 minutes using a Tyler sieve instrument (RX-29, Ro-Tap, W.S. Tyler, Mentor, Ohio, USA). Another sieve series was used (2, 1, 0.5, 0.25, 0.106, 0.053, and 0.023 mm) for the raw material before the granulation. Mean weight diameter (MWD, mm) was calculated following Kemper and Rosenau (1986). The size guide number (SGN, mm × 100) and uniformity index (Ui,%) were calculated according to CFI (2001).

Untapped bulk density (ρ_{bu}, kg m^{-3}) was measured using 1 L plastic cylinder (N'Dri-Stempfer et al. 2003) slowly hand-filled to reduce compaction. The cylinder was then tapped about 1300 times over 8 minutes with a modified sieving instrument (RX-29, Ro-Tap, W.S. Tyler, Mentor, Ohio, USA) to determine tapped bulk density (ρ_{bc}, kg m^{-3}). Granule density (ρ_g, kg m^{-3}) was measured by placing about 3 g of granules in a 50 mL glass pycnometer (Blake and Hartge 1986; Allaire and Parent 2004b). Each granule was coated with bee's wax, and kerosene was used as liquid. The reading was done within 30 seconds. Solid density (ρ_s, kg m^{-3}) was measured using a gas pycnometer (AccuPyc 1330, Micromeritics, Norcross, GA, USA). The porosity of untapped granules (ε_{Tu}, m^3 m^{-3}), tapped granules (ε_{Tc}, m^3 m^{-3}) and granules (ε_g, m^3 m^{-3}) was calculated using standard equations (Blake and Hartge 1986; Allaire and Parent 2004b).

$$\varepsilon_{Tu} = 1 - \frac{\rho_{bu}}{\rho_s} \tag{1}$$

$$\varepsilon_{Tc} = 1 - \frac{\rho_{bc}}{\rho_s} \tag{2}$$

$$\varepsilon_g = 1 - \frac{\rho_g}{\rho_s} \tag{3}$$

Crushing strength (τ, N mm^{-2}) was measured using a compression test apparatus (EZTest, Shimadzu, Columbia, MD, USA). A 1 mm^2 tip rod moved downward (100 mm min^{-1}) until the granule collapsed (i.e., slackness). Because only 1 granule was measured at a time, an average of four granules per replicate was used. Crushing strength values were then normalized according to granule diameter (Angers et al. 1987; Munkholm and Kay 2002).

Abrasion fragility (AF, g kg^{-1}) was measured using an adapted pharmaceutical method (Keleb et al. 2004; Kiekens et al. 1999). About 50 g of granules was sieved for 5 minutes using 1 mm sieve (RX-29, Ro-Tap, W.S. Tyler, Mentor, Ohio, USA). Granules were then placed into a drum and rotated for 5 minutes at 45 rotations per minute (±1 rpm) with 30 ball bearings (4.76 mm of diameter) (FRV-2000, Schleuniger Pharmatron, Manchester, NH, US). Samples were then sieved again to calculate AF, which

Table 1. Characteristics and separation procedures of solids from pig slurry and mixtures used before composting.

	Separation procedure†			Solid from pig slurry characteristics‡			Mixture§		
Compost	Physical	Coagulant	Flocculent	Dry matter	N	P	Solid from pig slurry	Peat	Other¶
				(%)			Ratio		
A	Centrifugal	Yes	No	34–55	25	65–70	1	0	1
B	Decantation	Yes	Yes	15–20	25	70	1	1	3
C	Rotary press	Yes	Yes	51–86	27–59	67–88	NA#	NA	NA
D	Screw press	Yes	Yes	70	2–4	70	2	1	3

†Separation procedures and technology used to separate the solid part from the slurry.
‡Percentage of the total pig slurry dry matter, N, and P found into the solid part (according to industrials).
§Volumetric ratios of pig slurry solid, peat, and other sources used before composting.
¶Other organic sources such as wood straws and leaves.
#Not available.

is the mass difference between fine particles (<1 mm) after and before abrasion treatment.

Granule water content [θ_g, g g^{-1} (dry matter)] was determined following AOAC (1995) method. Approximately 5 g of granules were placed in a desiccator with by Barium Oxide (BaO). The reading was done after a week of equilibrium. Water sorption from atmosphere (WSA, µg g^{-1} s^{-1}) was measured by placing 20 g of granules into an environmental chamber for 72 h at 20°C with humidity controlled at either 50, 60, 70 or 80% relative humidity. Primary results showed that 72 hours was sufficient to reach equilibrium. Water sorption rate from porous media (WSR, µg g^{-1} s^{-1}) was measured by installing 10 g of granules onto tension tables for 48 hours (Allaire and Parent 2004a). Fine nylon assured good contact between sample and glass bits. The tension tables represented near saturated (-0.07 m), very wet (-0.2 m) and moist (-1.0 m) soil moisture conditions.

Chemical properties

Chemical analyses were completed on each granule component (Table 2) and each replicate. Total nitrogen (N_{total}, g g^{-1}), total carbon (C, g g^{-1}) and total sulphur (S, g g^{-1}) were determined by dry combustion (CNS-Leco 2000). Because the C in the compost is mostly organic, total organic matter (OM, g g^{-1}) concentrations were calculated using equation 4 (Giroux and Audesse 2004).

$$OM = C*2 \tag{4}$$

Available phosphorus (P_2O_5, g g^{-1}) and potassium (K_2O, g g^{-1}) were extracted using the Newlon method. The calcium (Ca, g kg^{-1}), copper (Cu, mg kg^{-1}), iron (Fe, g kg^{-1}), magnesium (Mg, g kg^{-1}), manganese (Mn, mg kg^{-1}), and zinc (Zn, mg kg^{-1}) were extracted using acid digestion according to Barnhisel and Bertsch (1982) (Büchi Digest System K437, Büchi Labortechnik AG 1998, 2000 Flawil, Switzerland). The P_2O_5 was quantified by colorimetry according to Tandon et al. (1968). The Ca, Cu, Fe, Mg, Mn, and Zn were determined using atomic absorption spectroscopy, while K_2O and Na were determined using atomic emission spectroscopy (Analyst 200, PerkinElmer, Shelton, CT).

Statistical analyses

SAS-Stat software v.9.1 for Windows was used for statistical analysis (SAS 2000). Data were transformed when they were not normally distributed. Regressions (procedure REG) were completed only when correlation value between two properties was greater than 0.85. Several steps were completed to choose the physio-chemical properties to be used in step-wise regressions: (1) if a physical property correlated another property with $R^2 > 0.85$, it was used alone to predict that property and not entered into the stepwise regression; (2) if two

Table 2. Physico-chemical properties of compounds used for OMF granulation.

	OMF compounds						
	Compost						
Property	A	B	C	D	Peat	DAP‡	MAP§
Physical property							
MWD (mm)	0.64	1.25	0.94	0.78	0.63	0.29	0.23
ρ_{bu} (kg m^{-3})	495	293	325	358	129	841	792
ρ_{bc} (kg m^{-3})	608	392	435	468	179	1120	1192
ρ_s (kg m^{-3})	1759	1520	1558	1553	1533	1724	1862
ε_{Tu} (m^3 m^{-3})	0.72	0.81	0.79	0.77	0.92	0.51	0.57
ε_{Tc} (m^3 m^{-3})	0.65	0.74	0.72	0.70	0.88	0.35	0.34
θ_g (g g^{-1})	0.10	0.08	0.23	0.09	0.09	NA†	NA
Chemical property							
N_{total} (g g^{-1})	0.03	0.02	0.01	0.02	0.01	0.19	0.11
P_2O_5 (g g^{-1})	0.08	0.01	0.01	0.02	0.00	0.40	0.44
K_2O (g g^{-1})	0.01	0.00	0.00	0.01	0.00	0.00	0.00
OM (g g^{-1})	0.54	0.86	0.78	0.79	0.95	0.01	0.01
S (g g^{-1})	0.01	0.01	0.00	0.00	0.00	0.02	0.03
Ca (g kg^{-1})	72.6	20.9	23.9	50.5	2.5	3.4	3.2
Mg (g kg^{-1})	22.38	2.12	4.13	3.98	1.18	5.03	3.87
Fe (g kg^{-1})	6.33	7.74	4.54	3.87	1.41	10.10	7.82
Cu (mg kg^{-1})	439	228	146	191	6.4	4.4	2.8
Mn (mg kg^{-1})	1052	646	672	762	38	559	465
Zn (mg kg^{-1})	1209	648	492	1302	38	101	80
Na (mg kg^{-1})	2293	1018	1154	1359	352	1804	1704

†Not available.
‡Diammonium phosphate.
§Monoammonium phosphate.

Table 3. Descriptive statistics of physical and chemical properties of OMF granules.

Property	Symbol	Units	Mean	Min	Max	CV†
Physical property						
Untapped bulk density	ρ_{bu}	kg m^{-3}	559	349	754	20
Tapped bulk density	ρ_{bc}	kg m^{-3}	656	408	884	20
Granule density	ρ_g	kg m^{-3}	1231	899	1579	14
Solid density	ρ_s	kg m^{-3}	1665	1551	1779	4
Untapped porosity	ε_{Tu}	m^3 m^{-3}	0.66	0.52	0.78	9.65
Tapped porosity	ε_{Tc}	m^3 m^{-3}	0.61	0.44	0.75	12.40
Granule porosity	ε_g	m^3 m^{-3}	0.26	0.00	0.44	38.60
Size guide number	SGN	mm*100	366.5	359.1	372.3	0.5
Mean weight diameter	MWD	mm	5.89	5.35	6.22	2.22
Uniformity index	Ui	%	79.4	7.3	85.9	15.5
Abrasion fragility	AF	g kg^{-1}	0.13	0.03	0.53	78.80
Crushing strength	τ	N mm^{-2}	2.73	0.84	5.80	43.50
Water content	θ_g	g g^{-1}	1.92	0.56	4.26	43.20
Water sorption from soil	$WSR_{-0.07\ m}$	µg g^{-1} s^{-1}	3.93	0.66	10.18	45.00
	$WSR_{-0.20\ m}$	µg g^{-1} s^{-1}	3.63	0.53	16.20	51.00
	$WSR_{-1.00\ m}$	µg g^{-1} s^{-1}	2.40	0.06	5.95	51.60
Water sorption from atmosphere	$WSA_{50\%}$	µg g^{-1} s^{-1}	0.10	−0.05	0.24	72.00
	$WSA_{60\%}$	µg g^{-1} s^{-1}	0.12	−0.04	1.24	100.70
	$WSA_{70\%}$	µg g^{-1} s^{-1}	0.20	0.04	1.11	74.70
	$WSA_{80\%}$	µg g^{-1} s^{-1}	0.71	0.24	1.48	38.20
Chemical property						
Nitrogen	N_{total}	g g^{-1}	0.08	0.01	0.13	35.20
Phosphorus	P_2O_5	g g^{-1}	0.23	0.01	0.39	40.47
Potassium	K_2O	g g^{-1}	0.00	0.00	0.01	51.69
Organic matter	OM	g g^{-1}	0.4	0.0	0.7	46.4
Sulphur	S	g g^{-1}	0.02	0.00	0.02	28.63
Calcium	Ca	g kg^{-1}	16.4	2.4	75.0	86.5
Magnesium	Mg	g kg^{-1}	5.68	2.04	28.49	88.75
Iron	Fe	g kg^{-1}	7.39	3.82	12.31	20.96
Cupper	Cu	mg kg^{-1}	91	2	512	109
Manganese	Mn	mg kg^{-1}	545	294	1167	28
Zinc	Zn	mg kg^{-1}	404	35	1372	72
Sodium	Na	mg kg^{-1}	1495	917	2235	18

Note: The number of data for all parameters used varied between 144 and 153.
†Coefficient of variation.

Table 4. Polynomial regression coefficients describing the best relationships between some physical properties using mean weight diameter (MWD), untapped bulk density (ρ_{bu}), or water content (θ_g).

		Independent property			
Predicted property	Intercept	MWD	MWD^2	MWD^3	R^2
SGN (mm*100)	−298***	362***	−68***	4.3***	0.99
		ρ_{bu}	ρ_{bu}^2		
ρ_{bc} (kg m^{-3})	−85*	1.50***	−0.0003*		0.99
ρ_g (kg m^{-3})	434***	1.42***	ns		0.84
ε_{Tc} (m^3 m^{-3})	1.05***	−0.0009***	2.3 × 10 − 7**		0.96
ε_g (m^3 m^{-3})	0.71***	−0.0008***	ns		0.75
ln(τ) (N mm^{-2})	1.87***	0.0037***	ns		0.78
		θ_g			
$WSA_{80\%}$	0.397***	−0.078***			0.82

Note: The number of data for all parameters used varied between 143 and 150.
***, **, * and ns are significant at $\alpha < 0.0001$, 0.01, 0.05 and not significant, respectively.

Table 5. Stepwise regressions parameters described linear correlation between physical properties and physico-chemical properties of granule.

Dependent property	Intercept	Independent property	Estimate	R^2†
Relative to density				
ρ_{bu} (kg m^{-3})	−90.5*	Mg (g kg^{-1})	−11.1***	0.71
		Na (mg kg^{-1})	0.40***	
		Fe (g kg^{-1})	27.6***	
ρ_s (kg m^{-3})	1711***	Mg (g kg^{-1})	6.1***	0.61
		Na (mg kg^{-1})	−0.007*	
		OM (g g^{-1})	−200.4***	
Relative to resistance				
MWD (mm)	5.8***	Fe (g kg^{-1})	−0.023***	0.39
		S (g g^{-1})	19.0***	
Ui (%)	81.8***	Fe (g kg^{-1})	−2.94***	0.51
		Mg (g kg^{-1})	−0.97***	
		Na (mg kg^{-1})	0.029***	
		K_2O (g g^{-1})	−6673***	
τ (N mm^{-2})	−2.96***	Fe (g kg^{-1})	0.185***	0.46
		Mg (g kg^{-1})	−0.111***	
		Na (mg kg^{-1})	0.0083***	
Relative to water				
θ_g (g g^{-1})	4.50***	Na (mg kg^{-1})	−0.0019***	0.29
		Ca (g kg^{-1})	0.016***	
$WSR_{-0.20\ m}$ (µg g^{-1} s^{-1})	11.75***	ρ_{bu} (kg m^{-3})	−0.009***	0.66
		AF (g kg^{-1})	−4.72***	
		θ_g (g g^{-1})	0.456***	
		Mg (g kg^{-1})	0.133***	
		Na (mg kg^{-1})	−0.002**	
$WSR_{-1.00\ m}$ (µg g^{-1} s^{-1})	9.65***	ρ_{bu} (kg m^{-3})	−0.005***	0.75
		AF (g kg^{-1})	−2.55***	
		θ_g (g g^{-1})	0.064ns	
		Mg (g kg^{-1})	0.118***	
		Na (mg kg^{-1})	−0.003**	
$WSA_{50\%}$ (µg g^{-1} s^{-1})	0.269***	OM (g g^{-1})	0.555***	0.75
		θ_g (g g^{-1})	−0.019***	
		Na (mg kg^{-1})	−0.0002***	
		S (g g^{-1})	3.71ns	
		Mg (g kg^{-1})	0.009**	
$WSA_{60\%}$ (µg g^{-1} s^{-1})	0.007ns	OM (g g^{-1})	0.574***	0.35
		θ_g (g g^{-1})	−0.021*	
		Na (mg kg^{-1})	−0.002**	
		S (g g^{-1})	11.98*	
		Mg (g kg^{-1})	0.009**	
$WSA_{70\%}$ (µg g^{-1} s^{-1})	0.328***	OM (g g^{-1})	0.375***	0.72
		θ_g (g g^{-1})	−0.0085ns	
		Na (mg kg^{-1})	−0.0003***	
		S (g g^{-1})	7.74**	
		Mg (g kg^{-1})	0.014***	

Note: The number of data for all parameters used varied between 143 and 150.
***, **, * and ns are significant at $\alpha < 0.0001$, 0.01, 0.05 and not significant, respectively.
†Cumulative coefficient of determination for each predicted property.

properties were highly correlated, only one of them (the easiest to measure) was included in the regressions; and (3) if the correlation matrix indicated very low correlation between properties, the potential explicative property was not included in the regression. When properties were completely dependent, only the property with the higher correlation or the easiest to measure was included in the regression model.

RESULTS and DISCUSSION

Almost all physical properties (Table 3) were within the range found in literature. Size guide number values were slightly higher than those measured by Allaire and Parent (2003, 2004b) for different commercially available OMF. The SGN values of OMF granules were too large for mixing with other conventional granules (Hoffmeister 1982; Nielsson 1987) because most conventional fertilizers have SGN values around 220 (± 60) in Canada (CFI 2001). Nevertheless, OMF SGN values were slightly lower than the recommended range (400–700 mm) suggested to decrease fertilizer nutrient losses (Polyankov et al. 1985). However, the shape and size of the granules can be easily adjusted by changing the extruder-opening sieve. Tapped bulk density values were within the range measured by Allaire and Parent (2004b) for commercial OMF, whereas ρ_g values were slightly lower (899–1579 versus 1300–1700 kg m^{-3}) due to higher OM content trials used in this study. The range of porosities varied accordingly to densities because the density values were used to calculate porosities. Crushing strength values corresponded with those measured by Allaire and Parent (2004b). However, θ_g values did not correspond with Allaire and Parent (2004b) because we used negative pressure (i.e., vacuum) whereas no vacuum was used by Allaire and Parent (2004b). The WSA values corresponded with those measured by Allaire and Parent (2004a) for commercialized OMF, whereas the WSR values were 3 to 14 times higher in this study (0.7 to 10.2 versus 0.2 to 0.7 μg g^{-1} s^{-1}). Again, higher OM content trials used this study explain this difference. Therefore, under humid storage conditions, which is the case in most Quebec warehouses, high WSR values would negatively affect the granule integrity indicating that most of the OMF granulated in this study would require plastic packaging.

The MWD and ρ_{bu} are among the easiest, cheapest, and most important physical properties to measure. MWD can be used to predict SGN, while ρ_{bu} could be used to predict ρ_{bc}, ρ_g, ε_{Tc}, ε_g, and τ (Table 4). Therefore, these two parameters, which are easy and fast to measure, can predict five other physical properties of granules using simple polynomial equations. Many other correlations between physical properties were significant, but to a lesser extent (data not shown).

Chemical properties of OMF granules also affected several physical properties (Table 5). Iron concentration in OMF was one of the more important chemical properties because it affected ρ_{bu}, τ, and Ui (Table 5), which are important fertilizer physical properties measured in North America (CFI 2001; Hoffmeister 1979). Higher Fe content in OMF granules strongly increased its strength (higher τ) and density (ρ_{bu}), and decreased MWD and Ui values. However, using high-Fe organic substrates to improve physical characteristics of OMF granules is not suitable because it is known that Fe and P form relatively insoluble phosphate compounds (Larsen et al. 1958). Comparatively, higher Mg content tended to decrease the physical quality of the granules by decreasing ρ_{bu}, Ui, and τ (Table 5). Although less significant than Fe and Mg, Na content tended to increase ρ_{bu} and Ui and decrease ρ_s because Na is known to increase the hydration radius.

The granule OM content was the major property that affected WSA values (Table 5). Iron content did not have a significant impact on physical properties related to water, whereas Mg content increased WSA and WSR (Table 5). Low θ_g values increased WSA because the larger number of empty pores in the granules offers more volume for water transfer from air to granules. Although only significant for WSR at -0.2 m, θ_g increased WSR values; this is probably associated with the hydraulic property of the granules, which increases as the number of water- filled pores increases (Jury et al. 1991). Therefore, the dominant processes for both types of water sorption [rom the air (WSA) and from porous media (WSR)] were different. This trend was also observed by Allaire and Parent (2004a) on a wide range of mineral fertilizers and OMF. Finally, AF negatively affected WSR because low AF values increase the granule integrity; stable granules are able to absorb and store water using capillary rise and internal pores.

CONCLUSIONS

The physical properties of granulated OMF in this study had values similar to those found in other studies using commercially available OMF. MWD and ρ_{bu}, two easily measured properties, could be used to predict several other physical properties of granules that are more difficult to measure and calculate. Step-wise regressions showed that the physico-chemical properties (i.e., θ_g, AF, Fe, Mg, Na, and OM) of OMF affected several physical properties of OMF granules.

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