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Composition of Equine Manure as Influenced by Stall Management

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Abstract: A study was conducted to compare the composition of equine manure as removed from the stall, and bedding-free manure on six horse farms. The farms ranged from a pleasure horse stable with poorly managed stalls to an intensively managed stable for racehorses. The manure characteristics measured included: moisture content, total nitrogen, total ammoniacal nitrogen, nitrate nitrogen, organic nitrogen, total phosphorous (expressed as P_2O_5), total potassium (expressed as K_2O), calcium, magnesium, sulfur, zinc, copper, manganese, iron, total carbon, electrical conductivity (index of soluble salts), and pH. Statistical analysis indicated that stall management had a significant impact on the dry basis concentrations of all plant nutrients, carbon, organic matter, pH, and EC. It was also determined that the C:N of stall manure ranged from 23.4:1 to 48.5:1 depending on the amount of bedding used and daily management. The C:N value of equine manure was used as an indicator of the level of stall management (high, medium, low). It was determined that the concentrations of nitrogen, phosphorous, calcium, magnesium, zinc, copper, and sodium were negatively correlated with the C:N of horse manure. Average EC measurements ranged from 1.86 to 3.46 mmhos/cm. A correlation analysis, that included all metals that could be in salt form, indicated that EC was significantly correlated with the K_2O content but not with sodium, calcium, or magnesium. The high C:N values of horse manure indicated that composting may be a preferred method of treatment prior to land application. However, spreading equine manure based on the agronomic rate for P_2O_5 for a pasture and adding fertilizer nitrogen sufficient to reduce the C:N of applied manure to 10:1 to overcome induced nitrogen deficiency may provide another alternative.

Keywords: manure management; plant nutrients; organic matter; carbon; composting; land application

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1. Introduction

Horse ownership for sport and pleasure is very popular in the United States of America and Europe. Horse racing, polo, riding competitions, trail riding, fox hunting, and pleasure riding represent the most popular equestrian activities in the USA and the EU. A large portion of the horse population is kept on small farms that do not report annual income of more than 1000 USD per year. Consequently, the number of horses on farms in the USA that are reported by the US Census of Agriculture [1] is known to be below the actual number of horses kept on farms. According to the 2017 US Census of Agriculture, there were 2,847,289 horses on 459,526 farms in the USA [1]. However, surveys of horse owners in the US indicated that the actual number of horses was 7,246,835 or almost twice as many as indicated by the US Census [2]. A similar situation exits in the EU since many small horse farms are not included in national statistics. However, a survey of the equine population in EU countries indicated a horse population of about 6,990,000 in 2015 [3].

When most nutrient management planners or governmental regulators access the quantity of manure to be managed from farms in a state, the types of animals that are considered most often are swine, poultry, and cattle. The manure generated from stabled horses is sometimes overlooked. The amount of manure excreted (dung and urine) by a horse has been reported to range from 20.9 to 30.6 kg per day depending on the size of the horse and level of activity [4]. For a 500 kg horse, the typical daily manure production was estimated to be 24.9 kg/day [4]. Organic bedding, such as wood shavings or straw, is typically added to stalls to promote horse comfort and cleanliness and has been estimated to add 3.6 to 6.8 kg per horse per day [5], which is also counted as manure once soiled. Therefore, the amount of manure removed from a stabled 500 kg horse was estimated to range from 28.5 to 31.7 kg/day or 57.0 to 63.4 kg manure/1000 kg body mass/day.

Most of the efforts in the past were focused on quantifying the plant nutrient content of manure as-excreted from a horse. It has been shown that the total nitrogen content (TN) of excreted manure can range from 2.3% dry basis (d.b.) for sedentary horses to 3.2%, d.b. for very active horses [4,5]. The amount of P and K contained in manure excreted by very active horses was also higher than for sedentary horses ranging from 0.34 to 0.64% P, d.b. and 0.71 to 1.1% K, d.b. These differences in nutrient content were due to large differences in ration quality and daily feed intake between sedentary and active horses. While these data provided insight into the impact of ration on plant nutrient content of equine manure, knowledge of the composition of bedded horse manure as removed from the stable is preferred to provide more representative data to use equine manure as a commercial fertilizer substitute or as an ingredient for composting.

Mean plant nutrient content data for equine manure, as removed from the stall, were found in two publications [6,7]. One of the publications [6] provided mean nutrient contents based on 30 samples collected from horse farms in Kentucky, Colorado, Texas, and Oklahoma (USA) and Alberta, Canada and from four farms in New Jersey (USA). The amount or type of bedding used in the stalls was not reported. However, the TN contents ranged from 0.80 to 1.40%, d.b. and all were lower than the range reported for as-excreted horse manure (2.3 to 3.2%TN, d.b.; [4,5]). The lower concentrations of TN in as-removed manure may be the result of dilution from using organic bedding in the stalls. The mean concentrations of P ranged from 0.24% to 0.31%, d.b. and the potassium contents ranged from 0.99% to 1.00%, d.b. The tabulated means provided by ASABE [7] were 1.34% TN, 0.42% P, and 1.75% K, d.b. The impact of bedding on the total P and K contents was not as apparent since there was a significant overlap with the mean values reported for as-excreted horse manure [4,5]. The data from these sources indicated that horse manure also contained many essential minor plant nutrients including Ca, S, Mg, Fe, Mn, Zn, and Cu. Aluminum and sodium were also present; however, they are not essential minor nutrients and can be toxic to plants it they are present in the soil at high levels or if the soil has an excessively low pH.

A study in Finland [8] investigated the impact of the type of bedding used in horse stalls on the major plant nutrient contents. The results from this study demonstrated that the bedding used in the stalls was a source of TN, soluble-N, P, soluble-P, and K. The water-soluble N was reported to be the sum of ammonium-N (NH_4^+-N) and nitrate-N (NO_3-N) and accounted for 26.6% to 37.3% of TN depending on bedding type. Surprisingly, 48.1% to 60.0% of P was water soluble. Based on these results, it was hypothesized that stall management factors such as daily removal of manure and soiled bedding, the amount of clean bedding added per stall, and the frequency of stall use would have a significant impact on the plant nutrient contents of stall manure.

The carbon to total nitrogen ratio (C:N) is an important characteristic of horse manure that impacts how it can be used for composting. The C:N of horse manure as excreted has been reported to be about 20:1 [5]. The data provided by Krogmann et al. [6] and Keskinen et al. [8] indicated that manure removed from the stall had a C:N ratio ranging from 22:1 to 45:1 depending on bedding type. A near-optimal C:N for composting of equine manure is 30:1 [9]. Therefore, adjustment of C:N by adding a carbon source to low-C:N horse manure or adding a nitrogen source to high-C:N horse manure is often required to provide an optimal C:N for composting.

The high C:N ratio of horse manure has been shown to have a negative impact on the value of horse manure as a source of natural N fertilizer. Incubation studies performed by Keskinen et al. [8] and field data from Doesken and Davis [10] indicated that application of carbon-rich horse manure to soil reduced the amount of available N in the soil due to the immobilization of soluble nitrogen. The microorganisms in the soil consumed the soluble-N to decompose the large amounts of bioavailable carbon added by the high-C:N horse manure. These studies pointed out that horse manure is generally not an efficient N fertilizer and the plant nutrients that may be of beneficial use for soil improvement may be limited to P, K, and important minor nutrients such as S, Ca, Mg, Mn, and Fe.

The ration differences that are a related to horse activity level and the amount and type of bedding used to manage the stalls have both been shown to induce a large amount of variation in the amount of stall manure produced [4,5] and the plant nutrient composition [6,8]. The additional factor that could influence the composition of horse manure as removed from the stable was the frequency of stall use. The amount of time that horses are kept in a stall varies greatly depending on the purpose for which horses are kept. Horses that are kept for infrequent pleasure riding may only be confined in a box stall during extremely rainy weather, while others are allowed free-choice access to stalls or pasture. Horses kept for breeding, racing, or formal completion are often kept in stalls 8 to 12 h per day depending on training and completion schedule or weather conditions. In many cases, pleasure horses are kept only on pasture with no access to a stable and such a situation was not included in the scope of this study since such uncollectable manure would never be included in a land application plan or composting operation.

Given the wide variability in the frequency of stall use, the amount of bedding used in stalls, and other stall management factors such as schedule of stall clean-out, it was hypothesized that these factors would have a significant impact on the composition of equine manure. The objectives to meet this goal were: (1) collect as-removed bedded stall samples on six farms that kept horses for pleasure riding, breeding, and competition, (2) obtain bedding-free manure samples from three different farms, (3) classify each barn by level of stall management (low, medium, high), and (4) determine if stall management had a significant impact on the composition of equine manure.

2. Materials and Methods

Six horse farms were selected that included facilities that ranged from small, pleasure horse barns to farms with multiple barns that provided intensively managed housing for racehorses, pure-bred breeding stock, and horses used in hunt seat and jumper competition. Each horse farm was visited once to obtain manure samples. Samples were collected as manure and fouled bedding was removed from the stalls according to normal daily stall management practices. During the visit, the owner of the facility was asked questions about bedding practices, manure removal frequency, and stall use frequency. Observations were also made concerning the amount of bedding that was present in the stalls at the time of the visit.

Based on these interviews and observations during the visit, the farms were classified by stall management categories as shown in Table 1. Three facilities, Farms 1, 2, and 3, were classified as high for stall management since large amounts of bedding were used, and manure and fouled bedding were removed each day, and replaced with fresh bedding. These three farms had a high frequency of stall use since horses were typically kept in stalls overnight and during inclement weather. Farm 4 was ranked medium for stall management. The amount of bedding used fully covered the stall floors, but the stalls were not cleaned daily. In addition, the stalls were in generally good condition because the horses were kept on pasture most of the time. Farm 6 was placed in the medium stall management category since the amount of bedding used was not sufficient to fully cover the stall mats even though fouled bedding was removed each day and fresh bedding was added. Farm 5 was ranked low for stall management since stalls were not cleaned regularly and very little bedding was visible in the stalls and the stall surface was mostly packed dry manure. The horses in this facility spent most of the time on pasture.

Table 1. Description of the six horse farms and manure samples collected, and classification based on stall management.

Farm Number	Farm Description	Stall Management Category
1	Racehorses housed in a private barn, horses kept in the stalls overnight and during poor weather, generous amounts of wood shavings used, manure and foul bedding removed each day and replaced with wood shavings. Stall manure samples collected during daily stall cleaning.	High
2	Boarding facility for 50 pleasure horses, horses kept in the stalls overnight and during poor weather, manure and foul bedding removed each day and replaced with straw bedding. Stall manure samples collected during daily stall cleaning.	High
3	Boarding facility for 50–60 hunter/jumper horses, horses kept in stalls overnight, manure and foul bedding removed each day and replaced with wood shavings. Stall manure samples collected during daily stall cleaning.	High
4	Small boarding facility for pleasure horses predominately kept on pasture, stalls used infrequently, wood shavings and saw dust bedding added after removing manure and foul bedding as needed. Samples collected during visit. Stalls were not cleaned each day.	Medium
5	Boarding facility for 18 pleasure horses, box stalls used sporadically, stall surfaces were built up dry manure with very little bedding visible when samples were collected from the stalls. Stalls cleaned sporadically.	Low
6	Private barn for purebred brood mares, modern box stalls with rubber stall mats, horses kept in the stalls overnight and during poor weather, pelletized wood bedding, bedding amount used was not sufficient to cover the stall mats, manure and foul bedding removed each day with new bedding added. Stall manure samples collected during daily stall cleaning.	Medium
Manure Only	Bedding-free manure samples collected from stalls on Farm 2, 3, and 6.	NA [1]

[1] NA = not applicable.

While visiting Farms 2, 3, and 6, samples of horse manure without bedding were obtained from stalls to provide a comparison to heavily bedded horse manure. These samples were not as-excreted samples since they were of unknown age and generally did not include urine. However, in well-managed stalls, it was common for stall keepers to remove such bedding free manure to reduce daily bedding use.

Manure samples were collected from the stalls using a shovel and a wheelbarrow. Several samples were taken from several stall locations and added to the wheelbarrow to form a large composite sample. The manure was mixed well in the wheelbarrow using a shovel and a pitchfork. Three 2 to 3 L samples of the manure contained in the wheelbarrow were placed in sealed, plastic containers, and were transported on ice to Clemson University for analysis.

2.1. Sample Analysis

Three replicate analyses were performed for the bedded manure removed from each of the 6 horse barns and the bedding-free manure collected from the barns on Farms 2, 3, and 6. The samples were analyzed to determine the concentrations of total nitrogen (TN), total ammoniacal nitrogen (TAN = NH_4^+-N + NH_3-N), nitrate-N (NO_3-N), total phosphorous (P), total potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), and sodium (Na). The total P and total K were reported as P_2O_5 and K_2O to provide a better comparison with commercial fertilizers. Other characteristics measured included: moisture content, total carbon content (C), organic matter content (O.M.), pH, and electrical conductivity (EC).

Standard laboratory procedures were used for all analyses and details are summarized online by the laboratory director of the Agricultural Services Laboratory at Clemson University [11,12]. The concentrations of TN and C were determined from a dried and ground portion of the sample using the Elementar procedure. The ammonium-N concentrations were measured by mixing a representative 2 g sub-sample in a flask containing 20 mL of KCl (2 M) followed by standard digestion and acid titration techniques [11]. This method included the small amount of ammonia-N that was present in a manure sample. As a result, it provided a measurement of the total ammoniacal nitrogen (TAN). The NO_3-N content was determined using the cadmium reduction method for solid manures. The organic-N content was calculated as: Organic-N = TN − TAN − NO_3-N [11]. All the other elements (P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, and Na) were measured using ICP Mass Spectrometry [12]. The moisture content of all replicate samples was determined by drying a sub-sample in an oven maintained at 105 °C for 2.5 to 3 h and determining the weight of the dry matter fraction (DMF). The moisture content was calculated as: MC = 100 (1-DMF). The organic matter was determined by burning the dry sample in a 360 °C furnace for 2.5 h. The O.M. was the percent of the dry matter and was calculated as the difference between the dry weight and the ash weight divided by the dry weight. The pH was measured after mixing a 15 mL sub-sample with 15 mL of deionized water and soaking for 30 min. The pH of the solutions was measured using a pH analyzer. The electrical conductivity (EC) was determined by making a 1:5 dilution of the sample with deionized water. After allowing the slurry to equilibrate, an electrical conductivity meter was used to measure the conductivity in mmhos/cm.

2.2. Statistical Analysis

A simple one-way analysis of variance (ANOVA) was performed for each of the defined characteristics, and the total carbon to total nitrogen ratio (C:N). Each ANOVA had seven treatments with three replications yielding 14 error degrees of freedom. The least significant difference (LSD), using $t_{0.025,14} = 2.145$, was used to test for differences between treatment means at the 95% level of probability [13].

Based on the literature summarized previously [6–8], it appeared that the amount of bedding used had an impact on C:N. The C:N of a sample was selected as the independent variable to represent the level of stall management because the total carbon content was related to the bedding content of the sample and the total nitrogen content was related to the amount of manure in the sample. The O.M. was not used because carbon makes up a large portion of the organic matter and the remaining portion of the O.M. contained the organic-N. Consequently, it was hypothesized that the carbon to nitrogen ratio may be an index related to stall management. Linear correlation analysis was used to determine if the measured major and minor plant nutrients were significantly correlated to C:N for each of the 21 samples. Tabulated t-values were compared to t-values calculated using the following equation [13].

$$\text{t-cal} = r\,[(n - 2)/(1 - r^2)]^{0.5} \quad (1)$$

The variable n in Equation (1) was the number of replications (21), and r was the correlation coefficient. The minimum level of probability was 0.05. An equation of least-squares best fit was determined for all concentrations or properties of horse manure that were significantly correlated with C:N.

The electrical conductivity of manure, compost, or a soil amendment is often used as a general measure of the salt content. Elevated levels of EC can indicate that the material may be detrimental to plant growth. Many of the metallic plant nutrients contained in horse manure are from feed grains and minerals added to horse rations. All these metals are conductive to some extent and may be present in manure in chloride salt form (e.g., KCL, NaCL, $CaCl_2$, etc.). The electrical conductivity values of each sample were linearly correlated to the concentrations of Cu, Ca, Mg, Na, Zn, K_2O, Fe, and Mn. The correlation coefficients were tested for significance by comparing the calculated t-value (Equation (1)) with the tabulated t-values using a minimum probability level of 0.05.

3. Results

Statistical analyses of the carbon, organic matter, nitrogen, P_2O_5, K_2O, and minerals contained in the samples were performed on a dry basis since the moisture contents of the samples ranged from 58.3% to 77.0%. Such a wide range of moisture contents would introduce variation in concentration data that would otherwise need to be treated as a co-variant. The treatment means for the stall manure from the six different barns, and bedding-free manure are provided in Tables 2 and 3. The pooled standard deviations (s.d.) and the least significant differences (LSD) computed from the ANOVAs are also shown.

Table 2. Major plant nutrients, organic matter, carbon, moisture contents, and pH of horse manure. Treatment means with the same letter below were not significantly different. Comparisons were made across the rows.

Mixture of Bedding and Manure As Removed from Stall								
Farm No.	**1**	**2**	**3**	**4**	**5**	**6**	**Manure**	**LSD** [1]
Management Rank	**H**	**H**	**H**	**M**	**L**	**M**	**Only**	**(s.d.)** [2]
Moisture (%)	71.0 a	58.3 b	64.6 c	68.0 ac	67.5 ac	58.7 b	77.0	5.6 (3.21)
C:N	48.5:1	43.7:1 a	39.5:1 a	30.2:1 bd	23.4:1 c	34.3:1 d	27.5:1 bc	4.3 (2.44)
pH	7.50 a	8.23	7.23 a	7.63 a	7.73 a	7.73 a	6.87	0.29 (0.16)
O.M. (%, d.b.)	94.7	89.8 a	90.2 a	84.2 b	90.0 a	88.1 ac	86.1 bc	2.3 (1.30)
C (%, d.b.)	49.2 a	48.5 a	48.6 a	43.8	47.7 b	45.8	47.1 b	0.7 (0.41)
TN (%, d.b.)	1.02 a	1.11 a	1.23 ab	1.45 b	2.04	1.34 b	1.72	0.17 (0.10)
Org-N (%, d.b.)	1.01 a	0.85 b	1.09 a	1.41	1.87	0.99 ab	1.60	0.15 (0.08)
TAN (%, d.b.)	0.00 a	0.26 bc	0.13 b	0.03 a	0.16 b	0.35 c	0.10 ab	0.10 (0.057)
NO_3-N (%, d.b.)	0.0092 a	0.0035 a	0.0107 a	0.0102 a	0.0053 a	0.0053 a	0.0189	0.0079 (0.0045)
P_2O_5 (%, d.b.)	0.87 a	0.69 a	0.78 a	1.29 b	1.86	0.59 a	1.13 b	0.28 (0.16)
K_2O (%, d.b.)	1.05 a	1.14 a	1.20 ab	1.09 a	1.37 b	1.98	1.30 b	0.18 (0.11)

[1] LSD = least significant difference between treatment means (p = 0.05), 3 replications per treatment, $t_{0.025,14}$ = 2.145.; [2] s.d. = pooled standard deviation.

Table 3. Electrical conductivity and minor plant nutrient concentrations in horse manure. Treatment means with the same letter below were not significantly different. Comparisons were made across the rows.

Mixture of Bedding and Manure As Removed from Stall								
Farm No.	**1**	**2**	**3**	**4**	**5**	**6**	**Manure**	**LSD [1]**
Management Rank	**H**	**H**	**H**	**M**	**L**	**M**	**Only**	**(s.d. [2])**
Ca (%, d.b.)	0.39 a	0.43 a	0.43 a	0.71 b	0.84 b	0.68 b	0.46 a	0.18 (0.10)
Mg (%, d.b.)	0.19 a	0.18 a	0.20 a	0.41 b	0.42 b	0.29 c	0.29 c	0.06 (0.03)
S (%, d.b.)	0.14 a	0.19 b	0.14 a	0.18 ab	0.34 c	0.34 c	0.19 b	0.04 (0.02)
Zn (ppm, d.b.)	73 a	93 a	98 a	186	136 b	91 a	130 b	37 (21)
Cu (ppm, d.b.)	12 a	27 a	20 a	46 b	37 b	22 a	33 b	10 (6)
Mn (ppm, d.b.)	97	196 a	165 a	212 a	175 a	165 a	185 a	39 (22)
Fe (ppm, d.b.)	353 a	772 ab	624 a	4209	588 a	870 ab	1081 b	406 (232)
Na (ppm, d.b.)	349 a	420 a	389 a	1090	1317	454 a	451 a	185 (105)
EC (mmhos/cm)	1.54 a	1.86 ab	2.25 b	1.86 ab	2.41 b	3.46	1.80 ab	0.67 (0.38)

[1] LSD = least significant difference between treatment means, (p = 0.05), 3 replications per treatment, $t_{0.025,14}$ = 2.145. [2] s.d. = pooled standard deviation.

3.1. Farm-to-Farm Variability

One of the first things to notice from the treatment means in the tables (Tables 2 and 3) is that the composition of bedded horse manure collected at each of the six farms was significantly different from the others in one or more characteristics. Significant differences were observed in the concentrations of moisture, organic matter, TN, organic-N, TAN, P_2O_5, K_2O, minor plant nutrients, and sodium. Characteristics such as electrical conductivity, C:N, and pH also varied significantly from farm-to-farm.

3.1.1. C:N, Organic Matter, and Carbon

The C:N values ranged from 23.4:1, for the poorly managed stalls on Farm 5, to 48.5:1 for the intensively managed and heavily bedded stalls on Farm 1. Surprisingly, the mean C:N for bedding-free manure from three different farms averaged 27.7:1. It was expected that the C:N for bedding-free manure would be the smallest with a value on the order of 20:1. The C:N of the manure removed from the stalls with the highest level of management, Farm 1, was significantly higher than manure removed from all other farms in the study. The C:N values for the other two farms with a high level of stall management (Farm 2 and 3) were not significantly different and the average C:N for these two farms was 42:1. The mean C:N for the farms with medium bedding management (Farms 4 and 6) was 32:1. However, the mean C:N for Farm 4 was not significantly different than the C:N for un-bedded manure (manure only). In addition, the manure that was removed from the stalls on Farm 5 contained minimal bedding and was not significantly different from the bedding-free samples (manure only). These results indicated that the level of stall management had a significant impact on the C:N value of horse manure.

The percent of the dry matter removed from the stalls that was organic matter (O.M.) ranged from 84.2% to 94.7%. The highest O.M. content, 94.7%, was for samples collected from the farm with the best level of stall management (Farm 1). The other two farms with well managed stalls (Farms 2 and 3) were not significantly different and had an average O.M. content of 90.0%. It was expected that consistent manure removal and adding large amounts of beddings would consistently enhance the O.M. content. However, this expectation was not met since the manure removed from the stalls on the farm with poorly managed stalls with minimal bedding also contained 90.0% O.M. It appeared that the high O.M. was from the manure that was allowed to build-up in the stalls.

The fraction of the dry matter that was carbon was not statistically different for the three farms that were ranked high for stall management with an average of 48.8%. The two samples with no and minimal bedding were also not significantly different and averaged 47.4% C. The farms with the two lowest C contents (43.8% and 45.8%) were both ranked medium for stall management. Carbon accounted for a large portion of the O.M. in horse manure and it was calculated that 52.0% to 54.7% of the organic matter was carbon using the means given in Table 2. On the average, 52.8% of the O.M. (C/O.M.) in horse manure removed from the stalls on these 6 farms was carbon. Bedding-free manure had the highest fraction of carbon at 54.7% (C/O.M.).

3.1.2. Nitrogen and pH

The nitrogen content of horse manure was greatly impacted by stall management. The two treatments with the highest mean TN contents of 2.04% and 1.72% were for the samples with the least amount of bedding (Farm 5 and bedding-free manure) and were significantly different from each other and all other means. The lowest TN content, 1.02%, was for the manure removed from the most heavily bedded stalls (Farm 1). Most of the TN was in the organic form (Org-N) with the samples containing the least amount of bedding containing the largest concentrations of Org-N (1.60% and 1.87%). The TAN concentrations in horse manure were small and highly variable ranging from 0.0% to 0.35% across all means. Concentrations of nitrate-N were also very small and were not significantly different for manure removed from the stalls on all 6 farms. The mean NO_3-N concentration for manure removed from all stalls was 0.0074% d.b. The mean NO_3-N content for bedding-free manure was significantly higher than for manure removed from the stalls on all 6 farms (0.0189% d.b.) but was still small.

The pH of stall manure was not significantly different for the samples obtained from 5 of the 6 farms. The mean pH of the samples from these farms (1, 3, 4, 5, 6) was 7.56. Wood shavings, sawdust, and pelletized wood bedding was used in the stalls on these farms (Table 2). The bedding material used in the stalls on Farm 2 was straw and the average pH was 8.23. The pH of the bedding-free manure samples had a much lower pH of 6.87. These results suggest that addition of bedding increased the pH of horse manure, and that straw bedding increased the pH the most.

3.1.3. P_2O_5 and K_2O

The level of stall management had an impact on the mean concentrations of P_2O_5 that was similar to that of TN (Table 2). The stall manure that contained the least amount of bedding, Farms 4 and 5, and the bedding-free manure had the highest P_2O_5 contents indicating that using large amounts of bedding tended to have a dilution effect. In addition, the highest P_2O_5 concentration of 1.86% d.b. was for the poorly managed stalls (Farm 5) that contained no visible bedding and did not receive daily manure removal. The P_2O_5 content of the stall manure from the four best managed barns (Farm 1, 2, 3, and 6) were not significantly different and the mean for these 4 farms was 0.73% P_2O_5.

The average K_2O contents of the stall manure were not significantly different for the three farms with a high level of stall management (Farms 1, 2, 3) and Farm 4. The average K_2O content for manure removed from the stalls on these four farms was 1.12%. For some reason, the stall manure from the barn on Farm 6 was significantly higher in K_2O than all other treatment means at 1.98% K_2O. Based on the observations by Keskinen et al. [8], the source of the additional K_2O may have been the pelletized wood bedding used in these stalls (Table 1) or the horses in this barn may have been fed a ration with a higher potassium content. The manure samples that contained little to no bedding (Farm 5 and manure only) contained significantly more K_2O that the stall manure obtained from the most heavily bedded stalls (Farm 1 and 2). These results tend to indicate that using large amounts of bedding tends to reduce the K_2O content in a similar manner as for P_2O.

3.1.4. Minor Plant Nutrients, Sodium, and Electrical Conductivity

Significant differences in the concentrations of Na, S, and all the metals were observed for the means of all equine manure samples. The only pattern that was observed was that the mean concentrations of Ca, Mg, Zn, Cu, Fe, and Na were not significantly different for the manure removed from the stalls on Farms 1, 2, and 3. These were the stalls that received the highest level of stall management that included daily removal of manure and soiled bedding and the largest amounts of bedding added each day. A few of the other sample means shown in Table 3 were not significantly different from the samples collected on Farms 1, 2, and 3, but no other pattern was apparent in the available data. The variation in the concentrations in these elements was possibly variations in the concentrations in the rations fed to the horses, the bedding type, and any soil mixed into the manure from the stall surface.

The mean values of EC ranged from 1.54 to 3.46 mmhos/cm. Sodium was the element that was most likely to be in chloride salt form (NaCl) and would be expected to have the greatest impact on EC. However, no pattern between Na concentration and EC was apparent. For example, the Na content was 389 ppm and 1317 ppm for the samples collected on Farm 3 and Farm 5; however, the values of EC were not significantly different. Moreover, the stall manure with the highest EC of 3.46 had a relatively low sodium content of 454 ppm.

3.2. Correlation of Plant Nutrients with Respect to C:N

The C:N of horse manure removed from the stalls on these six farms tended to increase with stall management rank as can be observed in Table 2. It was also apparent that many, but not all, of the plant nutrients in horse manure appeared to have some dependency on the level of stall management. Linear correlation (y = bx + c) was used to determine if the composition of horse manure varied significantly with respect to C:N. The results of the linear correlation analysis using all 21 samples are summarized in Table 4. Equation (1) was used to calculate t-values using the correlation coefficient for each plant nutrient and the calculated values were compared to the critical t-values. The following plant nutrients were significantly correlated with C:N at the 0.01 level of probability: Org-N, TN, P_2O_5, Ca, Mg, Zn, and Cu. The only plant nutrient that had a significant correlation at the 0.05 level of probability was Mn. In addition, all the significant correlations were negative indicating that the daily manure removal and bedding use associated with better stall management appeared to have a diluting effect on plant nutrient contents.

Graphical analysis of the data for nutrients with a significant linear correlation coefficient indicated that the best fitting equation form was quadratic for TN, Org-N, and P_2O_5. A simple linear equation provided the best fit for Ca, Mg, Zn, Cu, and Mn. The coefficients of determination (r^2) and the regression equations are provided in Table 5. The critical values for r^2 given with the table were obtained from Steel and Torrie ([13] Table A13, p. 597).

The variation in TN, Org-N, and P_2O_5 contents with respect to C:N are shown in Figures 1 and 2 since all of these were best described by a quadratic equation. If the bedding used on these farms contained insignificant amounts of TN, Org-N, and P_2O_5, then a linear response would be expected since bedding would simply dilute the dry matter concentrations of the mixture of manure and bedding. However, the data provided by Keskinen et al. [8] indicated that bedding was a source of additional major plant nutrients. Therefore, the curvilinear form of the data plotted in these figures suggests that TN, Org-N, and P_2O_5 were added to these mixtures by the bedding used. Unfortunately, samples of unused bedding were not collected on these farms and the amounts of bedding used each day were unknown.

Table 4. Results of linear correlation analysis of concentrations of major and minor plant nutrients with respect to C:N (r = correlation coefficient).

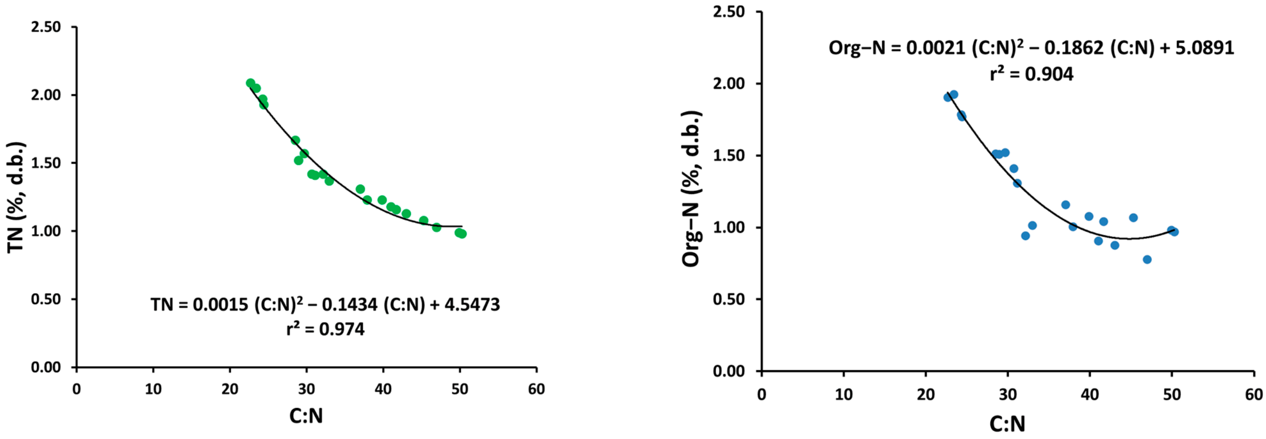
Constituent	r	Calculated t
TAN (%, d.b.)	−0.112	−0.490
NO_3-N (%, d.b.)	−0.125	−0.549
Org-N (%, d.b.)	−0.868 **	−7.629
TN (%, d.b.)	−0.946 **	−12.672
P_2O_5 (%, d.b.)	−0.719 **	−4.513
K_2O (%, d.b.)	−0.269	−1.220
Ca (%, d.b.)	−0.689 **	−4.144
Mg (%, d.b.)	−0.840 **	−6.747
S (%, d.b.)	0.062	0.273
Zn (ppm, d.b.)	−0.671 **	−3.940
Cu (ppm, d.b.)	−0.726 **	−4.604
Mn (ppm, d.b.)	−0.538 *	−2.785
Fe (ppm, d.b.)	−0.318	−1.464
Na (ppm, d.b.)	−0.399	−1.898

* Significant correlation, $|\text{t-cal}| > t_{0.05} = 2.093$.; ** Highly significant correlation, $|\text{t-cal}| > t_{0.01} = 2.861$.

Table 5. Least squared best fit results for plant nutrients with significant correlation with respect to C:N (r^2 = coefficient of determination).

Constituent	r^2	Equation of Least Squares Best Fit
Org-N (%, d.b.)	0.904 ***	Org-N = 0.0021 (C:N) ^{2} − 0.1862 (C:N) + 5.0891
TN (%, d.b.)	0.974 ***	TN = 0.0015 (C:N) ^{2} − 0.1434 (C:N) + 4.5473
P_2O_5 (%, d.b.)	0.767 ***	P_2O_5 = 0.0032 (C:N) ^{2} − 0.2697 (C:N) + 6.2837
Ca (%, d.b.)	0.475 **	Ca = −0.0147 (C:N) + 1.0815
Mg (%, d.b.)	0.706 **	Mg = −0.0097 (C:N) + 0.6239
Zn (ppm, d.b.)	0.450 **	Zn = −3.0843 (C:N) + 224.34
Cu (ppm, d.b.)	0.527 **	Cu = −0.9873 (C:N) + 63.1
Mn (ppm, d.b.)	0.290 *	Mn = −2.4103 (C:N) + 255.92

* Significant linear, r^2-critical (0.05) = 0.187. ** Highly significant linear, r^2-critical (0.01) = 0.301. *** Highly significant quadradic, r^2-critical (0.01) = 0.401.



(**a**) (**b**)

Figure 1. Variation in total and organic nitrogen content with respect to C:N of equine manure: (**a**) Total nitrogen (TN); (**b**) organic nitrogen (Org-N).

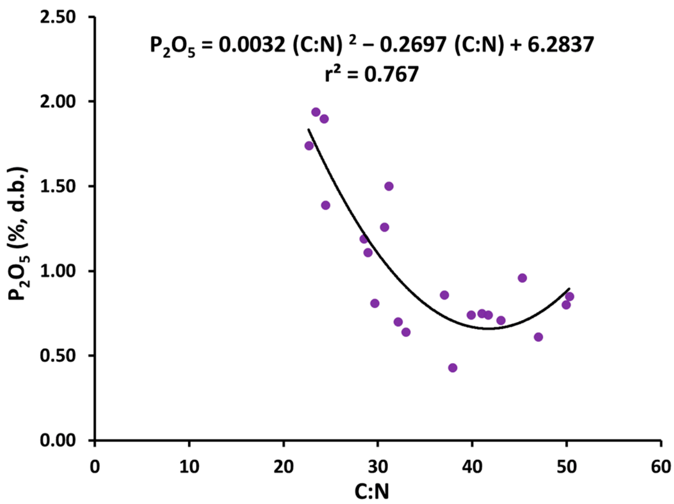


Figure 2. Variation in total phosphorous (P_2O_5) content with respect to C:N.

3.3. Correlation of Electrical Conductivity with Respect to Metal Contents

Electrical conductivity is often used as a general measure of soil amendment quality. In some cases, values of EC greater than 3.0 mmhos/cm indicated the presence of salts such as sodium chloride and may reduce seed germination or hinder plant growth [14]. However, a high EC can also be related to the presence of valuable plant nutrients or metallic minor nutrients that are electrically conductive. The mean values of EC obtained in this study ranged from 1.54 for manure collected from stalls bedded with generous amounts of wood shavings (Farm 1) to 3.46 for manure collected from stalls bedded with wood pellets (Farm 6). A correlation analysis was performed to determine which metallic elements in the horse manure were associated with increased EC values. The results of the correlation analysis are provided in Table 6. All the metals included could potentially exist in chloride salt form; however, many of these elements could also be complexed with sulfur. While Na would be expected to be present in the manure as NaCl, the values of EC were not significantly correlated to Na. Furthermore, the only plant nutrient that was significantly correlated with EC was K_2O. Therefore, the high EC values observed were directly correlated to high levels of natural potash fertilizer (K_2O). The variation in EC with respect to the K_2O contents for all 21 samples is provided in Figure 3 and the coefficient of determination was 0.612. These results demonstrate that EC alone cannot be used to determine if plant toxicity is likely, but sufficient analyses should be performed to determine if the elevated EC is from K_2O, a major plant nutrient, or Na.

Table 6. Results of linear correlation analysis of electrical conductivity measurements with respect to concentrations of metals that could potentially be in chloride salt form (r = correlation coefficient; r^2 = coefficient of determination).

Metals Measured	r	r^2	Calculated t
Cu	−0.057	0.003	−0.247
Ca	0.336	0.113	1.554
Mg	0.186	0.035	0.826
Na	0.094	0.009	0.413
Zn	−0.017	0.0003	−0.076
K_2O	0.782 **	0.612	5.474
Fe	−0.153	0.023	−0.673
Mn	0.071	0.005	0.309

** Highly significant correlation, $|\text{t-cal}| > t_{0.01} = 2.861$.

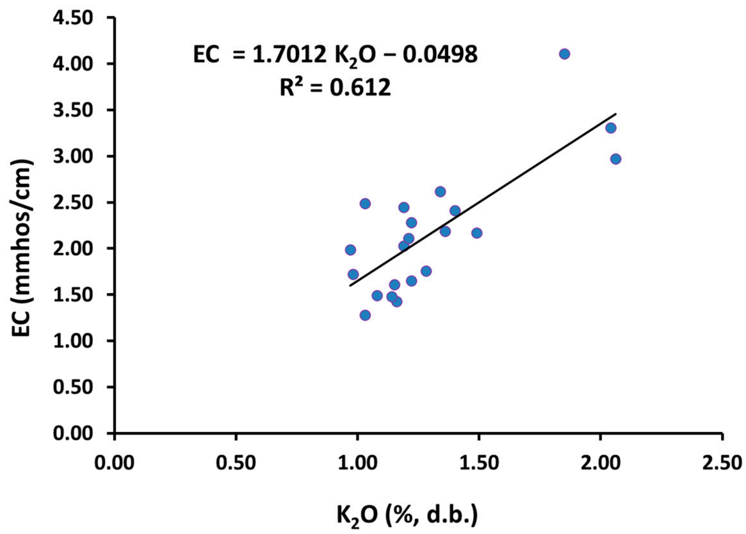


Figure 3. Variation in electrical conductivity (EC) with respect to K_2O.

4. Discussion

4.1. Comparison of Plant Nutrient Contents with Values from the Literature

The comparisons of sample means (Table 2) and correlation analysis (Tables 4 and 5) indicated that the TN and P_2O_5 concentrations of horse manure were significantly influenced by the level of stall management. Previous work on the TN and P_2O_5 contents of horse manure indicated that manure as excreted from active horses, such as racehorses or horses used in competition, had higher concentrations of TN and P_2O_5 than did sedentary horses [4,5]. The average TN and P_2O_5 contents of as-excreted manure for active horses were 3.2% TN and 1.5% P_2O_5, d.b. (P_2O_5 = 2.29 × 0.64% P, d.b.) [4,5]. Two of the barns included in the study (Farm 1 and 3, Table 1) were used to house active horses and also received a high level of stall management. The TN and P_2O_5 contents of the manure removed from these stalls (Table 2) were much lower than the average TN and P_2O_5 contents published for active horses [4,5]. The results for Farm 5 also provide another comparison of interest since these stalls were poorly managed for sedentary horses and contained a minimal amount of bedding. The mean TN and P_2O_5 contents for manure removed from the stalls on this farm were 2.04% TN and 1.86% P_2O_5 (Table 2). The mean TN and P_2O_5 contents of as-excreted manure for sedentary horses were 2.3% TN and 0.78% P_2O_5 (P_2O_5 = 2.29 × 0.34% P, d.b.) [4,5]. The much higher P_2O_5 concentration in the stall manure on Farm 5 was most likely from the large amount of manure that was allowed to build-up over time. These results point out that as-excreted manure composition values do not provide realistic data for planning environmentally responsible uses of equine manure for most farms.

The range of TN concentrations, from the literature, for manure removed from stalls was 0.80% to 1.48%, d.b. [6–8]. All of the manure samples collected from stalls that received a medium or high level of management in this study (Table 2) were within the published range for TN content. The mean of the samples collected from the stalls with a low level of management (Farm 5) was much higher at 2.04% TN and the bedding free samples, that corresponded to manure removed during daily cleaning, contained 1.72% TN on the average. The corresponding range of P_2O_5 concentrations from the literature was 0.46% to 0.97%, d.b. [6–8]. The P_2O_5 contents of stall manure collected on Farms 4 and 5, and un-bedded manure were much greater than the published range (Table 2). While the available as-removed values provided a better overlap with the data of the present study, these results suggest that values are needed that consider the amount of bedding used in the stalls, and the frequency of stall cleaning to more precisely manage the plant nutrients in horse manure.

The data collected in this study indicated that the amount of potassium (expressed as K_2O), S, Ca, Mg, Fe, Zn, Cu, and Na contained in stall manure samples varied significantly (Tables 2 and 3). The source of these elements are the grains, forages, and mineral supplements that are provided in the rations. Many of these elements are added as a mineral supplement mixed into the ration or provided in a mineral block that is offered free-choice to the horses. The variability in the concentrations of these elements was believed to be related to the fact that the actual amount of these nutrients consumed by horses on a farm is unknown. However, using large amounts of wood or straw bedding tended to dilute the concentrations of all these elements. Another source of K in stall manure may have been the pelletized bedding used as was observed for Farm 6 [8].

4.2. Forms of Nitrogen in Horse Manure and Ammonia Emission Potential

Most sources of data for the plant nutrient content of horse manure do not include information on soluble (TAN and NO_3-N) and organic nitrogen (Org-N). The primary exception was the study provided by Keskinen et al. [8] that found that 26.6% to 37.3% of the TN in bedded horse manure was soluble (TAN + NO_3-N). In the present study, the percentage of the TN in horse manure that was soluble ranged from 6.9% to 26.4% (Manure only and Farm 6, Table 2). Therefore, the majority of the total N contained in horse manure was in the organic form (73.4% to 93.1%).

The TAN content and the pH of horse manure would have a direct impact on the ammonia emissions from the manure produced on horse farms. Only the portion of TAN that was ammonia could be lost to the air in the barn or from a field after spreading as ammonia gas. Denmead et al. [15] provided the following equation to calculate the fraction of TAN that is in the ammonia form as a function of pH and the absolute temperature (K).

$$NH_3\text{-N}/TAN = 10^{\Phi}/(1 + 10^{\Phi}), \tag{2}$$

$$\Phi = pH - 0.0897 - (2729/K)$$

The fraction of TAN that is in the ammonia form is strongly dependent on the pH [15]. The value of (NH_3-N/TAN) ranges from 0 at a pH of 6.5 to 1.0 at a pH of 12. The ammonia fraction of TAN (NH_3-N/TAN) was calculated using Equation (2) at a temperature of 25 °C (298 K) with the three significantly different pH values from this study: 7.56 for stalls bedded with wood by-products (Farms 1, 3, 4, 5, 6), 8.23 for stalls bedded with straw (Farm 2), and 6.87 for bedding-free manure (manure only). Bedding-free manure had the smallest ammonia fraction of 0.004 or 0.4%, indicating that the potential for ammonia emission from manure removed from the stalls during daily cleaning was very small. The average pH for stalls bedded with wood by-products (pH = 7.56) was much greater and 2.0% of the TAN was in ammonia form. Use of straw bedding (pH = 8.23) increased the percentage of TAN that was ammonia-N to 8.8%. The mean TAN content in the manure removed from the stalls on this farm was 0.26%, d.b. (Table 2, Farm 2). Therefore, the $NH_{3_}$N content in the manure from Farm 2 was estimated to be 0.004%, d.b. The maximum estimated NH_3-N content in the study was for 0.007% for Farm 6 (Table 2) since the TAN content in the manure removed from these stalls was the greatest at 0.35%, d.b. Regardless of the type of bedding used it was concluded that the potential for ammonia emission from horse manure was small.

4.3. Beneficial Uses of Horse Manure

In most cases, manure from animal production facilities can be used as a good source of natural plant available nitrogen to grow forages, cereal grains, and other important crops. Using animal manure as a nitrogen fertilizer substitute requires estimation of the fraction of the TAN that will be conserved for plant use after spreading onto a field, and the amount of organic-N that will mineralized by soil microbes in a reasonable amount of time. However, horse manure has been shown to not be a good source of plant available nitrogen due to high C:N [8,10].

Several studies and current extension recommendations warn that applying un-composted horse manure to fields or gardens will cause immobilization of soluble nitrogen and will depress plant growth or crop yields [8,10,16]. Researchers at Colorado State University [10] compared the release of mineral nitrogen (NH_4^+-N + NO_3-N) with respect to time following application of urea, composted horse manure, bedding-free manure, and horse manure mixed with a large amount of bedding to pasture. They observed that un-composted horse manure released almost no mineral nitrogen until 166 days following application. In fact, un-composted manure mixed with 40% wood shavings by volume immobilized the largest amount of nitrogen post application. In contrast, composted horse manure released measurable amounts of mineral nitrogen up to day 111. It was also observed that composted and un-composted horse manure were not sufficient nitrogen substitutes for urea [10]. This was not surprising since only 6% to 12% of the organic-N in most compost products is mineralized during the first growing season [17].

Given the large amounts of bioavailable carbon contained in horse manure, it cannot be used as sufficient source of nitrogen in a similar manner as poultry litter (C:N = 9:1 to 12:1). Instead, the data in this study, and the information in the literature, indicate that it may be best to thoroughly compost horse manure to stabilize bioavailable carbon prior to use. After composting, the material should be applied based on agronomic rates for P_2O_5 or K_2O. Therefore, the primary benefit obtained by composting horse manure prior to application to soil would be to eliminate the problems associated with N immobilization while using the compost as a natural substitute for P_2O_5 and K_2O fertilizer. The compost will also provide many minor plant nutrients, such as S, Ca, Mg, Mn, Fe, Mn, Zn, and Cu, that are also essential for plant growth. Application of compost to the soil will also add significant amounts of stable organic matter and carbon that will add to soil structure and health.

However, producing a stable compost from horse manure requires additional costs in the form of facilities, labor, management, acquisition of N or C amendments to adjust the C:N to a value near 30:1, and energy. The funds and labor needed to make compost are often not available on horse farms. Therefore, another alternative is needed to provide an environmentally responsible and beneficial use of the horse manure that will be produced each year.

A less costly beneficial use of manure may be to apply un-composted horse manure based on the P_2O_5 or K_2O needs of a pasture or crop with enough nitrogen fertilizer, or natural N fertilizer, to offset the nitrogen demand to decompose bioavailable carbon. A horticulturalist in Ohio [16] recommended adding pure nitrogen fertilizer to horse manure prior to application to a field or garden to offset this problem. The recommended rate to overcome induced nitrogen deficiency was 5 kg of 34% ammonium nitrate fertilizer per metric ton of horse manure [16] or 1.7 kg of soluble N per metric ton. The application of fertilizer N (FN) with the manure would reduce the C:N of the mixture and has been shown to reduce the competition for N between the decomposing microorganisms and the plants [16]. Addition of 1.7 kg/mt of soluble N to the manures shown in Table 2 would decrease the applied C:N values from 23.4:1 to 48.5:1 to 8.7:1 to 17.9:1. That is, the C:N of the applied manure would be reduced to values similar to poultry litter in many cases. An improvement on this idea would be to adjust the addition of fertilizer N to yield a target C:N value based on the initial C:N of the horse manure. Therefore, the amount of fertilizer N (FN, kg/mt) needed to reduce the C:N of horse manure ($C{:}N_M$) to a specified target C:N ($C{:}N_T$) can be calculated as follows.

$$FN = (C{:}N_M / C{:}N_T) - 1 \quad (3)$$

Using a target C:N of 10:1, a common value for poultry litter, in Equation (3) indicated that the amount of FN needed would range from 1.34 kg FN/mt for stall manure with a C:N of 23.4:1 to 3.85 kg FN/mt for horse manure with a C:N of 48.5:1. The FN applied to the soil with horse manure to overcome induced nitrogen deficiency will increase the amount of fertilizer N needed for a pasture or crop.

The magnitude of the increase in nitrogen fertilizer requirements for this practice is best shown by a complete land application example. A common fertilizer recommendation for a cool season, perineal pasture is 112 kg N/ha, 45 kg P_2O_5/ha, and 45 kg K_2O/ha [18]. The amount of horse manure needed per hectare (MAR, mt/ha) to supply the agronomic rate for P_2O_5 was calculated for horse manure with the highest and lowest C:N ratios in this study (Farms 1 and 5). The resulting application rates for major and minor plant nutrients, organic matter, and carbon were calculated based on the manure application rate and the composition of the manure on a wet basis (kg/mt). The results of these calculations, as well as the equations used, are provided in Table 7. The manure with the higher C:N value had the lower P_2O_5 content of 2.53 kg P_2O_5/ha. As a result, 17.9 mt/ha were needed to apply 45 kg P_2O_5/ha. The manure with a lower C:N ratio contained over twice as much P_2O_5 and as a result, only 7.4 mt/ha were needed to meet the target of 45 kg P_2O_5/ha. The application rate for potash (kg K_2O/ha) for the high-C:N manure was slightly higher than the fertilizer recommendation of 45 kg K_2O/ha. Consequently, application of the manure from Farm 1 at a rate of 17.9 mt/ha would satisfy the P_2O_5 and K_2O fertilizer recommendations of the pasture along with useful amounts of all the minor nutrients as shown in Table 7. The other benefits would include generous amounts of O.M. and C. Application of 7.4 mt/ha of the low C:N manure (Farm 5) would provide 73% of the recommended rate for K_2O along with similar amounts of all minor plant nutrients. The greatest difference was in the lower application rates for O.M. and C, which were less than half the amount that would be provided by the high-C:N manure. The amount of sodium applied per acre was lowest for the high-C:N manure due to the dilution effect provided by the large amount of bedding used in the stalls. The amount of fertilizer-N needed to overcome induced nitrogen deficiency was calculated using Equation (3) and it was determined that application of high-C:N manure would require 69 kg FN/ha whereas the low-C:N manure would need only 10 kg FN/ha. The value of the P_2O_5, K_2O, minor plant nutrients, C and O.M. applied may provide cost savings to offset the cost of the additional nitrogen fertilizer.

Table 7. Manure and plant nutrient application rates if horse manure is applied to provide 45 kg P_2O_5/ha and fertilizer N sufficient to overcome induced nitrogen deficiency.

	Farm 1 C:N = 48.5:1, MC = 71.0% MAR [1] = 17.9 mt/ha Target C:N = 10:1 FN needed [2] = 3.85 kg/mt		**Farm 5 C:N = 23.4:1, MC = 67.5% MAR = 7.4 mt/ha Target C:N = 10:1 FN needed = 1.35 kg/mt**	
	Composition, kg/mt, w.b.	**Application Rate, kg/ha [3]**	**Composition, kg/mt, w.b.**	**Application Rate, kg/ha**
P_2O_5	2.52	45	6.05	45
K_2O	3.05	54	4.45	33
TN [4]	2.95	53	6.63	49
FN [5]		69		10
O.M.	274	4897	293	2177
C	142	2544	155	1154
Ca	1.13	20	2.72	20
Mg	0.54	9.7	1.38	10.2
S	0.40	7.1	1.10	8.1
Zn	0.021	0.38	0.044	0.33
Cu	0.003	0.06	0.012	0.09
Mn	0.028	0.50	0.057	0.42
Fe	0.102	1.8	0.192	1.4
Na	0.101	1.8	0.429	3.2

[1] MAR = manure application rate = Agronomic Rate for P_2O_5/P_2O_5 content of manure. [2] Fertilizer N needed to adjust applied C:N to target value using Equation (3). [3] Application rate = MAR × kg of nutrient/mt. [4] TN that a portion may become available slowly over time. [5] The Fertilizer N needed per acre = MAR × FN needed.

5. Conclusions

A study was conducted to measure the plant nutrient, organic matter, and carbon content of as-removed stall manure and bedding-free manure on six horse farms. Prior to analysis, stall management for each of the horse barns was classified as high, medium, or low based on the bedding frequency, and amount of bedding contained in the stall, and frequency of stall use. Statistical analysis of the organic matter, total nitrogen, P_2O_5, K_2O, organic matter, total carbon, and several minor plant nutrient concentrations indicated that the composition of manure collected from each of the barns was significantly different in one or more characteristics. These results point out that data collected from individual facilities are needed to account for farm-to-farm differences in feed composition, use of mineral supplements, stall management, and stall use.

In general, as the quality of stall management increased, the amount of bedding provided per stall per day increased, resulting in an increase in C:N from 23.4:1 to 48.5:1. It was determined that many of the major and minor plant nutrients were significantly negatively correlated with respect to C:N indicating a dilution effect from bedding.

Electrical conductivity is often used as a general measure of the salt content in manure, compost, and other soil amendments. The seven different treatments included in this study had EC values ranging from 1.54 to 3.46 mmhos/cm. A correlation analysis was used to determine which of the metals included in the analysis (Cu, Ca, Mg, Na, Zn, K_2O, Fe, Mn) were significantly correlated to EC. It was determined that the only plant nutrient that was a significant predictor of elevated EC values was K_2O content (dry basis) with a coefficient of determination of 0.612. Consequently, the high EC values observed were directly correlated to high levels of natural potassium fertilizer.

All the horse manure samples collected on the six farms studied contained large amounts of carbon as indicated by high values of C:N. As a result, horse manure was not assessed to be a good source of nitrogen as compared to poultry litter based on the results from previous studies [8,10,16]. The data in this paper indicated that horse manure should be stabilized by complete composting to decompose the large amount of bioavailable carbon prior to land application to prevent immobilization of soluble nitrogen in the soil. If composting is not practical, then spreading horse manure to supply the agronomic rate for P_2O_5 with enough fertilizer nitrogen to reduce the applied C:N to 10:1 was recommended. The value of the P_2O_5, K_2O, minor nutrients, organic matter, and carbon applied to the soil may offset the cost of the addition nitrogen fertilizer needed to overcome the expected immobilization of soluble N in the soil.

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