Environmental implications of nitrogen output on horse operations: A review

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16 Abstract

17 Nutrients such as nitrogen, which go unutilized during the digestive process, are then excreted into the
18 environment via urine, gas or fecal matter. Excess nitrogen released in this manner may contribute to a
19 reduction of the quality of air and groundwater sources. Many states have introduced or developed
20 legislation mandating nutrient management plans on livestock operations to reduce environmental nitrogen
21 losses. Strategies for reducing the environmental impacts of nitrogen on equine operations are two fold,
22 including a reduction in nitrogen inputs and better management of nitrogen outputs. The practice of
23 precision feeding, or feeding to accurately meet, but not exceed the nutrients requirements of an animal is a
24 plausible method for reducing nitrogen inputs. This approach is not widely implemented, as feeding protein
25 in excess of requirements is a common practice in the equine industry. Also, precision feeding is predicated
26 on a body of data containing the nutrient availability and digestibility in different feed sources; data which
27 are not fully elucidated in the horse. Management of nitrogen outputs on equine operations is largely based
28 on data extrapolated from other livestock operations as well as a few preliminary efforts on horse farms. The
29 potential impact of equine operations on nitrogen losses is explored in this review, shedding light on areas
30 where further research and management strategies are needed.

31

32 Keywords: horse, protein, nitrogen, lysine, digestibility, environment

33 1.0 Introduction

34 Feeding practices with the goal of precisely meeting the dietary requirement of the first limiting
35 amino acids (AA) have been implemented in many livestock systems to optimize performance and, recently,
36 to minimize nitrogen (N) excretion into the environment, for example the swine industry [1]. Paradoxically,
37 feeding protein in excess of requirement has been a common practice in the horse industry [2]. Fecal and
38 urinary nitrogen from livestock contributes to ground water contamination and decreased environmental air
39 quality [3]. With increasing public awareness and emerging regulations to limit nitrogen losses to the
40 environment, nutrient management plans may be mandated in the future to ensure sustainability of equine

41 facilities, especially in increasingly urbanized areas. Strategies to mitigate the impact of equine feeding
42 practices on the environment are contingent on knowledge of factors that impact protein utilization of
43 common feeds for equids. Due to the complexity of the equine digestive tract and the vast difference in feed
44 types, including forages and cereal grains, prediction of feed protein digestibility and nitrogen output
45 remains a challenge [4]. The goals of this review are to provide an overview of the current knowledge on
46 nitrogen utilization in equids in relation to the environment, and to identify knowledge gaps that preclude the
47 progress in designing prediction models of nitrogen excretion in equids. The specific objective of this
48 review is to assess the potential impact of nitrogen excretion from equids on the environment.

49

50 **2.0 Environmental implications of excreted nitrogen**

51 Nitrogen in the feces and urine must be managed to prevent consequences to the environment, such
52 as water contamination and decreased air quality [5]. Excess nitrogen in the air and water will eventually
53 reach larger bodies of water, where it can contribute to the deterioration of fisheries and fish habitats through
54 harmful nutrient loading [6]. Manure nutrients (nitrogen, phosphorus and organic matter) can be major
55 pollutants in lakes and estuaries as well as rivers. Nitrogen attached to eroded soil particles may reach
56 waterways through surface runoff or wind deposition. These waters, rich in nitrogen and other manure
57 nutrients promote a proliferation of plant life, especially algae. This process is called eutrophication [7].
58 Algae growth and the decomposition of organic matter in water bodies reduces the dissolved oxygen content
59 of the water, which may lead to fish kills, odors and other negative impacts on the aquatic ecosystem [8].
60 Though the larger environmental concern for nitrogen is surface runoff, nitrogen volatilization as ammonia
61 presents other problems including nonpoint source pollution through rain, and the effects of volatilized
62 ammonia on human health [9].

63 Nitrogen in manure can be converted to ammonia through bacterial degradation, primarily the
64 conversion of urinary urea to ammonia. Urease, an enzyme produced by microorganisms in feces, reacts

65 with urinary urea to form ammonia. Urease activity in feces is high; therefore urea is rapidly converted to
66 ammonia after excretion. It is the physical process of combining urine and feces after deposition on a floor
67 surface, which results in ammonia volatilization in the barn. Ammonia emissions (kg/LU; Livestock Unit
68 500kg live weight) are predicted to be lower in horses than in cattle, pigs, poultry, or sheep [10]; however,
69 ammonia emitted by horses is no less able to impact the environment on a unit-by-unit basis.

70 Other factors can influence ammonia volatilization in livestock housing. They include temperature,
71 air velocity, pH, surface area, manure moisture content, and storage time. For example, high pH and
72 temperature favor increased ammonia emissions. Horse manure pH typically ranges from 7.7 to 8.2 when
73 calculated from soiled stall waste, depending on the bedding source [11]. The pH of horse manure samples
74 collected between 2007 and 2014 and analyzed at the Pennsylvania State University Ag Analytical Services
75 Laboratory ranged from 6.9 to 8.2 with an average of 7.8, which allows for fairly rapid emission of ammonia
76 into the atmosphere [12]. Only a few studies have been conducted to calculate the amount of nitrogen and/or
77 ammonia concentration of horse stall waste, however, the amount will depend on a myriad of factors
78 including location, time of exposure and bedding type. Horse stables are noted to have higher ammonia
79 concentrations than pastures. This correlated with higher equine exhaled breath condensate pH in stables
80 compared to pastures [13]. One study looked at four different bedding types for the purpose of calculating
81 composting rate [11]. The study found that when long straw is used for bedding it has a higher percentage of
82 total nitrogen prior to composting than a pelletized straw and pelletized wood product. However, the amount
83 for long straw was not statistically different than when wood shavings were used for a bedding source. This
84 study also found that ammonia did not decrease after composting and therefore indicating that it was not
85 completely converted to nitrate or that the organic matter was not completely degraded by the composting.
86 Table 1 indicates nitrogen and phosphorus content of feces and different bedding sources from soiled stalls
87 in different studies.

88 The Environmental Protection Agency considers ammonia a threat to air quality because of
89 contribution to surface water eutrophication, nitrate contamination of ground water and the associated

90 impaired air quality [14]. Ammonia contamination has the potential for at least short-term adverse effects on
91 agricultural workers involved in animal care [15, 16]. Subjects in a study performed to simulate residing in
92 close proximity to a swine operation exhibited headaches, eye irritation, and nausea [16]. In studies of
93 workers at swine concentrated animal feeding operations (CAFOs), 25 % of the workers reported at least one
94 of the following respiratory symptoms; asthma, bronchitis, acute respiratory distress syndrome, and organic
95 dust toxicity syndrome [15]. However, as far as the authors know there has never been a study evaluating
96 the health of equine farm workers who are exposed to high levels of ammonia.

97 In a study conducted in horses fed at approximately 165% of the recommended protein amount [17],
98 authors showed that elevating protein levels in a horse's diet increases the ammonia and nitrogen levels
99 excreted in manure, the ammonia in the atmosphere, and the urea nitrogen in the animal's blood. More
100 specifically, fecal N and ammonia were higher (approximately 35 and 50 % higher, respectively) in the high
101 protein fed horses than in the control fed horses. Nitrogen and ammonia for control horses was 0.242 ± 0.01
102 and 0.034 ± 0.008 , respectively, while nitrogen and ammonia was $0.278 \pm 0.01\%$ and $0.068 \pm 0.008 \%$,
103 respectively, for horses fed high protein diets ($P = 0.015$). When atmospheric ammonia was tested by an 8-
104 hour accumulation via Dräger tube, there was a significantly higher level of ammonia in the air in the stalls
105 of horses fed the high protein diet. The high protein horses averaged 37.8 ± 3.4 ppm while the control horses
106 averaged 25.4 ± 3.4 ppm ($P = 0.029$) [17]. This could also lead to the question of horse health since these
107 Dräger tubes were placed on the noseband of the horses' halters over the course of an 8 hour period while
108 stalled. These levels could potentially be a problem for the horses' health if left exposed for an extended
109 period of time. A study in Japan found that a horse inhaling only 2 to 17 ppm of ammonia (range of
110 ammonia in an enclosed trailer) over the course of 40 hours created excessive nasal discharge and slight
111 swelling of the nasal cilia [18]. This same study found that another horse inhaling 40-130 ppm (maximum
112 exposure for humans) had a much more severe nasal discharge, swelling and irregular distribution of tracheal
113 epithelium and edema of the submucosa, loss of nasal cilia, and more severe swelling than the horse exposed
114 to 2-17 ppm. This study indicates that inhalation of these concentrations of ammonia is detrimental to the

115 respiratory health of horses. Future research should further investigate the possible negative consequence for
116 long-term exposure to ammonia using larger sample sizes.

117 Another study compared sawdust bedded stalls to paper bedding (recycled phone books) to
118 investigate the ammonia differences and horse health over a 14-day period [19]. Ammonia samples were
119 taken from an air pump placed at horse nose height for a period of 30 seconds and found the ammonia levels
120 were higher with the sawdust bedding (1.42 – 2.54 ppm) compared the paper bedding (0.21 – 0.88 ppm).
121 However, horse health variables (e.g. endoscopic examination of the nasal passage and trachea, tracheal
122 wash cytology, tracheal inflammation, and general health observations) did not differ between bedding types.
123 Pratt et al. [20] found that when using straw bedding instead of rubber mats ammonia concentrations rose to
124 a peak of 14 ppm after 14 days in the same stalls; stalls were cleaned each day. This study did not find any
125 respiratory or health complications with horses exposed to this level of ammonia. However, it is possible
126 that diet may effect nutrient excretion in the context of environmental contamination, air quality and horse
127 health. More research is needed to evaluate the effect of different feeding strategies on nutrient excretion in
128 the context of environmental contamination and air quality.

129

130 **3.0 Defining a need for managing nitrogen input and output on horse operations**

131 Animals acquire nitrogen from protein in the feedstuffs they eat. A substantial amount of organic N
132 is excreted in urine or feces, as it has been estimated that less than 45% of consumed protein is utilized and
133 made into animal protein [21, 22]. It has been shown that horse owners commonly over feed protein, up to
134 150% of the recommended requirements [2]. In a survey conducted by Harper [23], horse owners fed their
135 horses 161% of NRC [24] CP requirements on average. Maintenance horses were associated with greater
136 overfeeding than working horses. Maintenance horses require fewer nutrients than working horses [24];
137 however, they often received the same type of concentrate as their working counterparts on any given farm,
138 just in smaller amounts. Those concentrates often have higher concentrations of nutrients than required for
139 maintenance, which leads to excessive nutrient supplementation and therefore nutrient excretion. Usually,

140 maintenance horses can be sustained on forage only diets [25]. Excess protein in the horse diet is then
141 excreted in sweat, feces, and urine (Figure 1).

142 There are several situations when excessive protein or an imbalance can occur. A forage ration
143 consisting primarily of excellent quality hay typically has excessive levels of protein and soluble protein.
144 Formulating feed rations with higher than required protein levels, to ensure all essential amino acid
145 requirements have been met often compounds the problem. It is possible to meet minimum requirements for
146 crude protein while being deficient in single amino acids [24]. When this occurs, whole body protein
147 synthesis might be limited [26]. Depending on the actual performance level of the horses, this can result in
148 excessive levels of nitrogen being fed and excreted. Furthermore, in many operations a single diet is fed to
149 all horses without consideration of activity levels or physiological states of individual animals. This practice
150 could lead to over- or under-supplementation of individual animals and poor overall nitrogen management.

151 A few studies have looked at reducing the CP concentration of horse rations through supplementation
152 of purified limiting amino acids. Lysine added to linseed meal and brewers dried grain diets with hay has
153 increased foal weight gain and feed conversion efficiency [27, 28]. Staniar et al. [29] reduced the CP level
154 of a supplement to 9% while fortifying with lysine and threonine to growing Thoroughbreds on pasture. For
155 the overall observational period no differences in physical growth measurements were observed in the
156 crystalline amino acid supplemented group (9% CP) compared to the control (14% CP).

157 Feeding excess dietary nitrogen not only is of consequence to the environment, but also to the animal
158 and cost of the diet. There is a metabolic energy cost associated with excreting excess nitrogen in the urine,
159 making diets with excess protein inefficient and not cost effective. Additionally, higher protein diets can
160 affect acid-base balance [30], heat production [31], and water requirements [30]. All of these factors are of
161 particular concern to the athletic horse.

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163
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165 **4.0 Nitrogen content of common equine feedstuffs**

166 Digestibility of a protein and absorption of its amino acid constituents are the main determinants of
167 protein quality and the predictor of utilization for maintenance or productive functions by the animal as
168 compared. Domesticated equids are fed a wide variety of feeds ranging from herbage to seeds. The
169 composition of proteins and their availability for digestion vary extensively across feeds, thus rendering
170 prediction of nitrogen excretion difficult.

171 Nitrogen in equine diets comes from forages, grains and oil seed meals. Legume forages generally
172 have higher CP concentration than grasses, ~20% vs 11 to 13% CP DM basis [32]. Within grasses, cool
173 season grasses generally have higher CP concentration (average of 15% CP on an DM basis) than warm
174 season (11% CP DM basis) [32]. Although the CP concentration of grains does not vary as greatly as that of
175 forages, it can differ between cultivars. Wheat cultivars can range from 13-15% CP [33]. Oilseed meals
176 have greater CP concentration than grains. Soybean meal, cottonseed meal and linseed meal are about 51, 44
177 and 36 % CP on a DM basis, respectively [32].

178 Several factors influence the protein content of plants. Plant maturity plays a role with immature
179 forage plants having greater protein content than more mature plants as reviewed by Pagan [34]. For
180 instance, CP content of alfalfa decreased from 15% to 9% after 20 additional days of growth [35].
181 Fertilization and management practices additionally influence the nitrogen content of forage with greater
182 amounts in grasses receiving fertilizer and regular clipping [36]. Fertilization can also increase the CP
183 concentration of grains [37, 38]. Crude protein and nitrate concentration of common horse feeds are outlined
184 in Table 2.

185 Sources of nitrogen in feedstuffs include protein nitrogen and non-protein nitrogen (NPN)
186 compounds. Stage of maturity may affect the amino acid profile of alfalfa [39], but red clover and grass
187 amino acid profiles may not be as influenced by maturity [40]. Some grain cultivars have altered amino acid
188 characteristics. Breeding for specific characteristics can change the relative proportions of proteins present

189 in the plant resulting in an altered amino acid profile. One such example is a high fat oat cultivar [41].
190 There are also high lysine corn cultivars that have been specifically developed to improve feed value [42,
191 43].

192 One of the most common forms of NPN in plants are nitrates, and much of the nitrogen absorbed
193 from the environment and therefore utilized by plants, is in the form of nitrates. Factors affecting nitrate
194 accumulation in plants including level of nitrogen fertilization, forage species, maturity, herbicides, and light
195 intensity, have been reviewed by Crawford et al. [44] and by Wright and Davison [45]. Some forms of
196 nonprotein nitrogen are commonly added to ruminant diets as reviewed by Huntington [46]. Urea is a type
197 of NPN that is minimally utilized by equids [47-49]. Unlike ruminants, NPN compounds are not added to
198 practical equine diets; because the majority of the microbial population and bacterial protein synthesis is
199 distal to the small intestine, horses are not as efficient at utilizing these forms of nitrogen [50].

200 Selecting feedstuffs containing appropriate protein and nitrogen profiles to meet the horse's dietary
201 needs may help to reduce nitrogen outputs through strategic selection of inputs.

202

203 **5.0 Nitrogen balance**

204 A Whole Farm Nutrient Balance [14] assessment is a tool that can be used to determine generation of
205 excess nutrients on farm and can be useful in developing plans to manage nutrient buildups. This idea may
206 be helpful for reducing nitrogen losses in equine production. The challenge is to manage the animals, crops,
207 and other farm components to efficiently use available manure nitrogen, and reduce potential losses to the
208 environment [51]. Nutrient accumulation occurs when nutrient inputs exceed nutrient outputs [52]. Whole
209 farm balances of inputs and outputs can be used to assess the risk of non-point source pollution and identify
210 pollution reduction strategies [53]. Nutrient balances can be calculated on several levels including regional,
211 whole farm, and field scales [54].

Whole farm or “farm gate” nutrient balances compare the nutrients of concern, which come in and go out of the farm gate [55]. Products typically going onto a farm through the gate include purchased hay and grain or concentrates, mineral fertilizer, manure, bedding, and live animals [55]. Products typically leaving a farm through the gate include crops, eggs, milk, meat, fiber, live animals, and manure [55].

A Pennsylvania State University study [23] which followed 14 Mid-Atlantic horse farms for an entire year, found that whole farm balances on Mid-Atlantic horse farms averaged 73% for nitrogen, which is similar to findings in other species. Kohn [56] reported that whole farm nitrogen balance averaged 66% on high efficiency dairy farms. Percentage is an indicator [57] of the proportion of nitrogen inputs (feed, fertilizer, animals, and legume nitrogen) not accounted for in the outputs (crops, animal products, and manure). As a point of reference, a lower percent would mean a higher or poorer balance for the farm. On horse farms, there may be a wider range of nitrogen balance values due to the amount of manure horse farms export. In the Pennsylvania State University study [23], horse farms exporting all their manure averaged 39% balance for nitrogen; and they reported that all farms imported some feed. The mean farm balance for those that did not export any manure was 100%, indicating that all nitrogen imported onto the farm remains on the farm. Determining nitrogen balance will always be more of a challenge on horse farms since there are a variety of types of operations, including breeding, boarding, performance and pleasure, etc. [58] often having a high turnover rate of horses; a Rutgers University study [59] found that an average of only 5 of 13 horses remained on 20 farms sampled after one year (most left the farm, some were removed due to age, disease, physical defect, etc.). Manure that remains on pasture when horses are grazed can be substantial and will also influence balance calculations, and is complicated if rotational pastures are poorly maintained. Finally, the amount of manure exported can either help or hinder a farm’s balance depending on the amount exported.

Whole farm nutrient balance is critical for managing nitrogen losses in the environment. As this issue has gained public awareness, several states have developed legislation to manage balance on farms. Depending on the individual state’s definitions of “farming”, many equine operations are not factored into

the nutrient balance equation. Many hobby or small farms, which may have high nonpoint source pollution potential, may not be accounted for if they do not hit the threshold of “farming” definitions. In New Jersey, any facility with less than eight horses is encouraged, but not required to establish and follow an animal waste management plan [60], while Vermont’s new small farm regulations accounts for larger farms, not regulating any farm using less than ten acres, and/or those where farming is not considered a business [61]. It is important to realize that current legislation may help to mitigate some nitrogen losses on targeted operations, though livestock farms including horse farms of any size can have an impact on the environment. Farms with compacted soil, bare patches of pasture or with manure storage located near ground water sources should be managed to mitigate potential environmental impacts [62].

The Netherlands was the first country to research and develop methods to reduce environmental impact of livestock operations. Their programs focused on three solutions 1) reduce nutrient inputs in when fed in excess of requirements, 2) apply practical management solutions to reduce nutrient usage of outputs on farm, and 3) increase manure that is exported off farm [5]. These are all programs that have been previously tested and implemented on many concentrated animal-feeding operations (CAFOs) in the United States [51], and have plausible implications on horse farms. Hauling manure off the property can improve farm balance although neighboring crop farms have to be willing to work with the producer [57]. However, equine research and implementation is much slower to follow. It has been reported that most horse farms in the Chesapeake Bay area export nearly 50% of their manure [58, 63] found that 58% of New Jersey horse farms disposed of some or all manure off-site while 54% of survey farms spread some manure on their farms.

256

257 **6.0 Challenges to precision feeding nitrogen in the horse industry**

In a Pennsylvania SARE Project Report [64], farm managers reported it was very difficult for horse owners to balance horse rations. Most farms used a commercial mixed feed concentrate that could not be adjusted. However, one farm with 70 horses reported that all horses were on individual diets. Most farms reported feeding hay from different weekly truckloads and did not produce hay on farm. In most cases, farm

managers are unable to make major feed ration adjustments due to these reasons. Concentrates often include more CP than is required to ensure that individual amino acid and CP requirements have been met when the concentrate is fed with a variety of forages with different CP and amino acid contents. However, caretakers of animal species should be able to incorporate best management practices (BMPs) that help to reduce nitrogen excretion. A major deterrent in reaching a nearly perfect balance is feed cost and profit [51]. However, in the horse industry, the deterrent appears to be management traditions, convenience, and a lack of independence. In the equine industry, feed and supplement cost is less of an issue, especially on non-commercial or pleasure horse operations. This is an important consideration since most horse farms fall in this category. For example, the average size of horse farms in Minnesota participating in a pasture management program was 10 acres with 5 horses [65].

When attempting to procure a valid figure on equine nitrogen excretion in light of multiple quantities and types of feedstuffs provided at any given equine operation, the most logical places to evaluate or attempt to calculate prediction equations are going to be based on either feed consumed or in fecal nitrogen levels excreted. Zeyner and Kienzle [66] used data from over 250 digestion trials to establish a predictive formula to estimate digestible nutrients in equine feed rations. They were able to confirm a strong uniformity of crude protein, demonstrated through linear regression of digestible crude protein by total consumed crude protein. Utilizing this information and resulting formula calculation ($DCP = -2.27 + 0.917 \times CP$), allows equine nutritionists to calculate a reasonable nitrogen excretion value based upon feed intake of horses on farms. Mesochina et al [67] evaluated in vivo digestibility data from horses fed 27 different forage diets to create prediction equations for crude protein and other dietary parameters for horses grazing on pasture or rangeland. They reported that fecal crude protein and dietary fiber were the best predictors of diet digestibility. However the most accurate estimates of diet digestibility were determined when dietary variables such as dietary crude protein and fiber were included in the calculations. Readers should be cautioned that these approaches may not be reliable predictors in horses that are fed low protein or excessively high protein diets.

7.0 Programs and Regulations

In addition to the myriad of intrinsic reasons for managing horses to minimize nitrogenous impacts on the environment, horse owners, especially in populated areas near watersheds, recognize regulations imposed by government. While all horse farms fall under the jurisdiction of the Federal Animal Feeding Operation (AFO), which is administered and regulated by the Environmental Protection Agency (EPA), many states have begun developing and passing laws which require higher standards than the federal requirements. Most of these recommendations and/or regulations pertain to limiting nonpoint source pollution of state waters and fall under the jurisdiction of the state level agricultural agencies. Whether they use terms such as Animal Waste Management, BMPs, Accepted Agricultural Practices, most contain requirements and limits for direct animal access to waterways, manure storage and/or application, and grazing near wells, neighboring property and state waters. Recently, Vermont passed legislation [61] which extends requirements to small farms. In the past Vermont required permitting for Medium (150-499 horses) and Large (500 or more horses) Farm Operations. This water quality bill includes a certification for Small Farm Operations, which are currently defined as farms “on which 10 or more acres are used for farming”, and have no more than 149 horses and the lower limit has yet to be determined by the Secretary of Agriculture, Food, and Markets. While farms falling under these guidelines are required to submit annual certification of compliance, the law extends to any farm, which potentially provides a threat to water quality through potential threat of discharge or contamination of groundwater. In addition, there are sections which will allow for compliance inspection at any time, and require water quality training for eight hours over each five year period on topics including prevention of discharges, mitigation and management of storm water runoff, land application of manure or nutrients, nutrient management planning, and other farm compliance rules and regulations.

Horse farms may pose an environmental risk of nonpoint source pollution since they often have higher stocking rates than can be accommodated by natural methods of nutrient absorption. In 2011, the Pennsylvania Department of Environmental Protection [68] mandated that farms with as few as one animal

312 fitting the livestock classification (e.g. horse, goat, sheep) must document the adherence to guidelines and
313 submit a farm manure management plan. Maryland has incorporated horse operations, which bring in
314 \$2,500 in gross annual income and/or have eight or more horses under the Water Quality Improvement Act
315 of 1998 [69]. New Jersey has tiered requirements for developing animal waste management plans, with
316 larger farms (>300 animal units) requiring a Comprehensive Nutrient Management Plan, medium farms (299
317 to 8 animal units) completing a self-certified plan and smaller farms being encouraged, but not required to
318 complete one [60]. Pending regulations for all horse farms across the United States is a significant issue
319 Land Grant University Extension services should be prepared to proactively address through educational
320 programs for horse owners. This could be a major undertaking since the last American Horse Council report
321 indicated there were 9.2 million horses and 1.96 million horse owners in the U.S. [70].

322 The United States Department of Agriculture Natural Resources Conservation Service (NRCS) is
323 offering an Environmental Quality Incentives Program (EQIP) [71] to help farms in the Chesapeake Bay area
324 improve feed management. By helping farmers formulate their rations more accurately to meet their herd's
325 production requirements, these partners (agencies and universities) are helping farmers decrease the nutrients
326 that are excreted while maintaining or improving livestock production and health. These feeding
327 adjustments can help farmers reduce nitrogen excretions by 30-50%. The EQIP incentives include payments
328 and provided assistance and cost share help to farms for ration balancing. Both Pennsylvania and New
329 Jersey have begun incentivizing equine operations/managers in these programs.

330 331 **8.0 Conclusions**

332 There are a myriad of factors at play in nitrogen utilization in horses and the impact on the
333 environment. Management of horses and the associated nitrogen inputs and outputs is critical to prevent
334 negative environmental consequences such as decreased air quality and water contamination. Precision
335 feeding and waste management are strategies that can minimize nitrogen excretion and environmental
336 contamination. Feed choices and combinations affect nitrogen availability and absorption in the

337 horse. Selection of feeds that are more efficiently utilized by horses, and feeding to meet, but not exceed the
338 dietary protein and nitrogen requirements of a horse is paramount. This will require an understanding of
339 feed choices and equine digestion, in addition to behavioral modifications in terms of resisting the tendency
340 to feed more than is necessary.

341 In addition to feeding behavior changes, it is important to develop some sort of integrated decision
342 support systems (DSS) that are more applicable to the needs of horse operations. Karmakar et al [72]
343 reviewed many types of DSS programs and procedures available from academic institutions and industry, yet
344 most of these were intended for or aimed at more traditional livestock operations. Several key decisions
345 revolve around returning the nutrients to the land to maintain nitrogen balance, yet many horse operations
346 have neither adequate land nor machinery to manage the manure in this manner. An effective DSS guidance
347 tool for equine operators would take into consideration the complexities involved in a livestock business,
348 which often includes managing many animals on an individual basis belonging to individual owners.
349 Additional considerations including potentially high stocking rates, contracted bin removal for manure
350 disposal, and equine business type would need to be incorporated. Finally, calculations and methodology are
351 needed for creating and locating adequate storage, covers or roofing for manure piles, drainage and gutter
352 installation to divert runoff or groundwater around, rather than through, the manure in fields and storage
353 sites.

354 Because of transportation, storage, and application losses, diet management is an important
355 component of whole farm nitrogen management in keeping water and atmospheric losses at a minimum
356 [51]. Reducing dietary nitrogen has been shown to reduce both ammonia runoff and volatilized
357 nitrogen. Precision feeding can achieve those results without sacrificing production. Further investigation
358 into CP, lysine and other amino acid requirements of horses is also an essential component of moving
359 towards more efficient feeding. Studies detailing the actual requirements of horses at maintenance and
360 various physiological states will enable a movement away from exceeding requirements due to feeding based
361 on predictive regressions. Current legislation in several states incentivizes or requires horse owners to

362 develop more precise feeding strategies or to manage their farms to reduce potential negative consequences
363 of nitrogen on the environment. Even though related legislation has not yet been enacted in all states, the
364 evidence of the potential environmental implications of horse and other livestock operations should provide
365 horse owners with incentive for incorporating best management practices in feeding and manure
366 management on their farms.

367

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372 Figure 1: Nitrogen utilization by the horse as adapted from Tanner (2014).

373

374 The dotted arrow line indicates that the importance and proportion of AA uptake in the hindgut after the
375 digesta has interacted with the largest portion of the microbial population remains largely unknown.

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380 Table 1. Concentrations of ammonia gas (NH₃ gas), ammonium (NH₄), total nitrogen (N), nitrate and pH collected from various
381 studies. Cells with empty (-) values were not tested in a given study.

Study reference	Experimental Conditions	Bedding or treatment types	NH ₃ gas (ppm)	NH ₄ (ppm)	Total N %	Nitrate (ppm)	pH
Komar et al., 2011 (Mean ± SE)	Soiled bedding collected from stalls for 30 days	Pelletized Straw	-	10.1 ± 2.65	0.71 ± 0.04	0	7.8 ± 0.1
		Long Straw	-	14.6 ± 2.65	0.94 ± 0.04	0	8.2 ± 0.1
		Pelletized Wood	-	13.5 ± 2.65	0.63 ± 0.04	0	7.7 ± 0.1
		Wood Shavings	-	17.1 ± 2.65	0.78 ± 0.04	0	7.9 ± 0.1
Williams et al., 2011 (Mean ± SE)	Feces only collected for 5 days from horses on a low or high protein diet	Feces only low protein diet	25.4 ± 3.4	300 ± 80	0.24 ± 0.01	-	-
		Feces only high protein diet	37.8 ± 3.4	700 ± 80	0.28 ± 0.01	-	-
Fleming et al., 2008 (Mean ± SD)	Feces and urine added to containers under standardized conditions with bedding for 14 days	Wheat Straw	237 ± 118	530 ± 168	-	10 ± 17	-
		Wood Shavings	207 ± 116	805 ± 235	-	0	-
		Hemp	193 ± 114	842 ± 81	-	162 ± 58	-
		Linen	178 ± 88	783 ± 47	-	0	-
		Straw Pellets	80 ± 51	377 ± 68	-	0	-
		Paper Cuttings	217 ± 120	843 ± 54	-	0	-
Garlipp et al., 2011 (Mean ± SE)	Feces and urea added to containers with bedding under standardized conditions for 19 days	Wheat Straw	5.75 ± 0.8	-	1.07 ± 0.07	-	6.9 ± 0.11
		Rye Straw	4.07 ± 0.8	-	1.14 ± 0.07	-	6.8 ± 0.11
		Wood Shavings	2.31 ± 0.8	-	0.61 ± 0.07	-	6.4 ± 0.11

382

383 Table 2. Concentration range (average) of Crude Protein (CP), Nitrates (NO₃) and Nitrate-
384 Nitrogen (NO₃-N) in common equine feedstuffs.^a

Feedstuff	% CP	% NO ₃	ppm NO ₃ -N	% Nitrate
Dry Forage				
Legume Hay	18.6-23.9 (21.3)	0.0005-0.35	10.56-788.2	0-0.19
Grass Hay	7.0-14.6 (10.8)	0-0.69	0-1563	0-0.24
Bermudagrass Hay	8.2-13.6 (10.9)	0-0.25	0-567.8	0-0.16
Straw	2.8-7.6 (5.2)	0-1.48	0-3341	0-0.04
Wheat Hay	6.8-14.3 (10.5)	0-0.53	0-1202	0-0.17
Fresh Forage				
Mixed mostly Grass Pasture	10.9-25.1 (18.0)	0-0.23 (0.038)	0-511 (85.7)	0-.57 (0.193)
Grass Pasture	7.9-22.8 (15.4)	0-0.15 (0.052)	0-341 (116.4)	0-0.44 (0.153)
Grains				
Barley	9.6-14.1 (11.9)	0.01-0.01 (0.01)	22.17-22.17 (22.17)	0.003-0.003 (0.003)
Beet Pulp	7.5-11.1 (9.3)	0-0.05 (0.022)	0-116.9 (48.94)	0.004-0.02 (0.012)
Corn	7.5-10.6 (9.0)	0	0	0.008-0.008 (0.008)
Oats	10.5-14.6 (12.5)	0	0	0.02-0.02 (0.02)
Rice Bran	10.6-18.7 (14.6)	0	0	0
Soybean Meal	46.4-56.0 (51.2)	0-0.17 (0.004)	0-36.9 (9.63)	0.004-0.004 (0.004)
Soybeans	34.9-44.8 (39.9)	0	0	0
Wheat	11.0-16.1 (13.6)	0-0.01 (0.003)	0-28.5 (6.60)	0

385

386 ^aData obtained from Equi-Analytical Laboratories, Ithaca, NY, Common Feed Profiles.
387 <http://equi-analytical.com/interactive-common-feed-profile/>. Accumulated crop years of 2000-
388 2014.

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