UNIVERSIDADE ESTADUAL DE MARINGÁ
CENTRO DE CIÊNCIAS AGRÁRIAS

# IMPACTO AMBIENTAL DO SISTEMA DE PRODUÇÃO DE SUÍNOS ATRAVÉS DA ANÁLISE DE CICLO DE VIDA: EFEITO DA REDUÇÃO DO CONTEÚDO DE PROTEÍNA BRUTA DA DIETA PARA ANIMAIS EM CRESCIMENTO

Autor: Lucas Antonio Costa Esteves
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Tese apresentada, como parte das exigências para a obtenção do titulo de DOUTOR EM ZOOTECNIA, no Programa de Pós-Graduação em Zootecnia da Universidade Estadual de Maringá – Área de concentração Produção Animal.

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TITULAÇÃO: Doutor em Zootecnia - Área de Concentração Produção Animal

APROVADO em 14 de julho de 2020.

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Profª Drª Alessandra Nardina Trícia Rigo Monteiro

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Prof. Dr. Paulo Cesar Pozza
Orientador

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# BIOGRAFIA

Lucas Antonio Costa Esteves, filho de Natalino Lineu Esteves e Thais Terezinha Galvão Costa, nasceu em Birigui, Estado de São Paulo, Brasil, no dia 5 de novembro de 1987.

Em fevereiro de 2008 ingressou no curso de graduação em Zootecnia, na Universidade Estadual de Maringá, onde se diplomou em dezembro de 2012.

Em março de 2013, iniciou no programa de Pós-Graduação em Zootecnia, em nível de mestrado, área de concentração Produção Animal, na Universidade Estadual de Maringá, atuando na área de "Avaliação de alimentos para suínos". Em fevereiro de 2015, obteve o título de Mestre em Zootecnia.

No período de 2015/2016, atuou como técnico, fazendo visitas e auxiliando produtores na região de Maringá. No segundo semestre de 2016, começou a cursar matérias como aluno não regular no Programa de Pós-Graduação em Zootecnia da Universidade Estadual de Maringá.

Em março de 2017 ingressou como aluno regular no doutorado em Produção Animal do programa de Pós-Graduação em Zootecnia da Universidade Estadual de Maringá. Aprovado pelo Exame Geral de Qualificação em dezembro de 2019.

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# RESUMO

Objetivou-se neste trabalho utilizar a análise de ciclo de vida (ACV) para avaliar o impacto ambiental da produção de suínos em crescimento nas fases de 30 – 50 kg e de 50 – 70 kg, alimentados com dietas com redução de proteína bruta (PB) e suplementação de aminoácidos industriais. No primeiro trabalho (30 – 50 kg), foram realizados dois experimentos. Experimento I (balanço de nitrogênio e fósforo): foram utilizados 20 suínos machos castrados com peso médio inicial de 31,80 ± 2,39 kg, alojados em gaiolas metabólicas e distribuídos em um delineamento experimental de blocos ao acaso, com quatro tratamentos e cinco repetições, sendo um animal por unidade experimental. Experimento II (desempenho): foram utilizados 44 suínos machos castrados, com peso médio inicial de 30,10 ± 0,63 kg distribuídos em delineamento experimental de blocos ao acaso, com quatro tratamentos e 11 repetições, sendo um animal por unidade experimental. Os tratamentos utilizados nos dois experimentos consistiram de quatro dietas contendo 18,15; 17,15; 16,15 e 15,15% de PB, e suplementação de aminoácidos industriais, de forma que as exigências de todos aminoácidos digestíveis fossem atendidas. A partir dos dados obtidos nos experimentos (Experimentos I e II) os impactos para as categorias mudança climática (MC), potencial de acidificação (AC), potencial de eutrofização (EU), demanda acumulada de energia (DAE), ecotoxicidade terrestre (ET) e ocupação de terra (OT) foram calculados, sendo a unidade funcional representada por um kg de ganho de peso vivo (kg de GPV). Houve redução dos impactos ambientais para algumas categorias quando a PB dietética passou de 18,15 para 15,15%, observando uma redução para a AC de 35,34 para 31,58 g $SO_2$-eq (P=0,015), também foi observada redução para a EU, reduzindo de 11,90 para 10,31 g $PO_4$-eq (P=0,001), assim como OT reduziu de 2,15 para 1,89 $m^2$-year (P=0,005), respectivamente. Embora tenham sido observadas variações para as categorias MC, DAE e ET, não houve diferença significativa entre os tratamentos avaliados (P>0,05). No segundo trabalho, também foram realizados dois experimentos. No experimento I (metabolismo), foram utilizados 20 suínos machos castrados com peso médio inicial de 63,62 ± 2,21 kg, alojados em gaiolas metabólicas e distribuídos em um delineamento experimental de blocos ao acaso, com quatro tratamentos e cinco repetições, sendo um animal por unidade experimental. No experimento II (desempenho), foram utilizados 40 suínos machos castrados, com peso médio inicial de 49,92 ± 0,92 kg distribuídos em delineamento experimental de blocos ao acaso, com quatro tratamentos e dez repetições, sendo um animal por unidade experimental. Os tratamentos utilizados nos dois experimentos consistiram de quatro dietas contendo 16; 15; 14 e 13% de PB, e suplementação de aminoácidos industriais de forma que as exigências de todos aminoácidos digestíveis fossem atendidas. Para o desempenho, espessura de toucinho e profundidade do musculo *longissimus lumborum* não foram observadas diferenças (P>0,05) entre os tratamentos avaliados. A ureia plasmática foi menor (P<0,05) para os animais alimentados com as dietas com redução proteica, assim como a excreção de N urina e N total, mas não foram observadas diferenças (P>0,05) para N retido, P absorvido, P ingerido e P fezes. Para as categorias potencial de eutrofização (P=0,051) e ocupação de terra (P=0,063), a redução proteica mitigou os impactos ambientais quando utilizou-se os dados referentes ao farelo de soja produzido na região sul, porém a redução proteica proporcionou aumento no impacto quando a categoria avaliada foi a de demanda acumulada de energia, tanto para análise realizada considerando-se a soja produzida no sul (P=0,003), quanto para a produzida na região centro oeste (P=0,044). Conclui-se que a redução da proteína bruta e suplementação de aminoácidos industriais em dietas para suínos em crescimento (30 - 50 kg) reduziu os impactos ambientais para as categorias acidificação, eutrofização e ocupação de terra, contudo para suínos em crescimento (50 – 70 kg) a redução proteica promoveu menor impacto para as categorias potencial de eutrofização e ocupação de terra, porém, para a demanda acumulada de energia, o efeito foi oposto, tanto para a análise realizada utilizando-se a soja produzida na região sul, quanto a produzida na região centro-oeste.

Palavras-chave: Acidificação, aminoácidos, nitrogênio.

# ABSTRACT

The aim of this work was to use life cycle assessment (LCA) to analyze the environmental impact of growing pig production in the 30 - 50 kg and 50 - 70 kg phases, fed with diets with reduced crude protein (CP) and supplementation of industrial amino acids. In the first work (30 - 50 kg) two experiments were carried out. Experiment I (nitrogen and phosphorus balance): 20 barrows with an average initial weight of 31.80 ± 2.39 kg were used, housed in metabolic cages and distributed in a randomized block design with four treatments and five repetitions, one animal per experimental unit. Experiment II (performance): 44 barrows, with an average initial weight of 30.10 ± 0.63 kg, were distributed in a randomized block design with four treatments and 11 repetitions, one animal per experimental unit. The treatments used in the two experiments consisted of four diets containing 18.15; 17.15; 16.15 and 15.15% CP, and supplementation of industrial amino acids so that the requirements of all digestible amino acids were met. From the data obtained in the experiments (Experiments I and II) the impacts for the categories global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO) were calculated, with the functional unit represented by one kg of live weight gain (kg of LWG). There was a reduction in environmental impacts for some categories when dietary CP increased from 18.15 to 15.15%, observing a reduction for AP from 35.34 to 31.58 g SO2-eq (P = 0.015), it was also observed reduction for EP, reducing from 11.90 to 10.31 g PO4-eq (P = 0.001), just as LO reduced from 2.15 to 1.89 m2-year (P = 0.005), respectively. Although variations were observed for the categories GWP, CED and TE, there was no significant difference between the treatments evaluated (P> 0.05). In the second work, two experiments were also carried out. Experiment I (metabolism) 20 barrows with an initial average weight of 63.62 ± 2.21 kg were used, housed in metabolic cages and distributed in a randomized block design with four treatments and five replications, one animal per experimental unit. In experiment II (performance) 40 barrows were used, with an initial average weight of 49.92 ± 0.92 kg distributed in a randomized block design, with four treatments and ten repetitions, one animal per experimental unit. The treatments used in the two experiments consisted of four diets containing 16; 15; 14 and 13% CP, and supplementation of industrial amino acids so that the requirements of all digestible amino acids were met. For performance and carcass characteristics, no differences were observed (P> 0.05) between the treatments evaluated. Plasma urea was lower (P <0.05) for animals fed diets with protein reduction, as well as the excretion of N urine and total N, but no differences (P> 0.05) were observed for retained N, P absorbed, P ingested and P fecesFor the categories of eutrophication potential (P = 0.051) and land occupation (P = 0.063) the protein reduction mitigated the environmental impacts when using data referring to soybean meal produced in the southern region, however the protein reduction provided an increase in impact when the category evaluated was that of cumulative energy demand, both for analysis performed using soy produced in the south (P = 0.003) and for that produced in the central west region (P = 0.044). It was concluded that the reduction of crude protein and supplementation of industrial amino acids in diets for growing pigs (30 - 50 kg) reduced the environmental impacts for the categories acidification, eutrophication and land occupation, however for growing pigs (50 - 70 kg) kg) protein reduction promoted less impact for the potential categories of eutrophication and land occupation, however, for the cumulative energy demand the effect was opposite, both for the analysis carried out using the soy produced in the southern region and that produced in the Midwest region.

Keywords: acidification, amino acids, nitrogen.

# I-INTRODUÇÃO

O aumento da população mundial, podendo chegar a aproximadamente 10 bilhões de pessoas no ano 2050, representa um desafio ao setor produtivo, uma vez que a demanda de alimentos, entre estes os alimentos de origem animal, irá se intensificar (FAO, 2017). O aumento da renda e a mudança no comportamento da população, principalmente em países em desenvolvimento, irão proporcionar o aumento do consumo de carnes. Neste cenário de crescimento populacional, a cadeia de produção de suínos tem grande importância. No Brasil o consumo de carne suína no ano de 2019 foi 15,3 kg per capita (ABPA 2020).

O Brasil tem grande importância no cenário de produção e exportação de carne suína, visto ser o quarto maior produtor e também o quarto maior exportador deste produto. A quantidade exportada no ano de 2017 foi de 697 mil toneladas, ficando atrás apenas de União Europeia, Estados Unidos e Canadá, sendo que a quantidade exportada representa 8,5% das exportações mundiais deste mercado (ABPA, 2018). O rebanho de suínos no Brasil no ano de 2018 foi composto por 38,8 milhões de animais, ficando atrás apenas do rebanho da China (440,6 milhões), União Europeia (150,3 milhões) e Estado Unidos (73,2 milhões) (Statista, 2019).

Para se manter entre os maiores produtores e exportadores mundiais, o país deve incentivar a capacitação e a especialização deste setor. Além da busca em melhorias em nutrição, genética e sanidade, deve-se procurar também alternativas para que a produção seja ambientalmente sustentável. Diante disso, o Ministério da Agricultura Pecuária e Abastecimento, com apoio do Instituto Interamericano de Cooperação para a agricultura (IICA), elaborou o Projeto Suinocultura de Baixa Emissão de Carbono (BRASIL, 2016).

O Projeto Suinocultura de Baixa Emissão de Carbono tem como premissa promover o uso racional da água e dos alimentos e avaliar e difundir alternativas economicamente viáveis para o tratamento de dejetos na suinocultura. A compostagem e a biodigestão são processos que podem ser utilizados para o tratamento dos resíduos gerados, e têm como benefício, a geração de subprodutos. A compostagem tem como produto final um material rico em nitrogênio (N), fósforo (P) e potássio, que pode ser utilizado como fertilizante e substituir adubos químicos (BRASIL, 2016).

A biodigestão tem como produtos finais o biofertilizante e o biogás, rico em metano ($CH_4$), que pode ser queimado e utilizado para geração de energia. O benefício do biogás é que, ao ser queimado, o metano que possui potencial 25 vezes mais poluente em termos de aquecimento global, em relação ao gás carbônico ($CO_2$), não será mais emitido à atmosfera (IPCC, 2006). O processo de queima do metano gera o crédito de carbono, que pode ser comercializado com países que possuem metas de redução de emissão de gases de efeito estufa (ABCS, 2014).

O manejo correto dos dejetos é uma forma eficiente de se reduzir o impacto ambiental causado pela produção de suínos, mas é uma ação pontual que pode ser considerada uma solução do tipo *end-of-pipe*. Implementar outras técnicas ao longo da cadeia de produção, pode potencializar os efeitos benéficos ao ambiente. Mudanças na composição nutricional podem melhorar o aproveitamento de nutrientes e diminuir a excreção de elementos ao meio ambiente. Se a nova dieta promover o melhor aproveitamento dos nutrientes e melhor desempenho dos animais, o tempo necessário para os animais atingirem o peso desejado será menor e, com isso, o impacto ambiental poderá ser mitigado devido à menor demanda de alimento, água e energia utilizada na produção.

A redução da proteína bruta (PB) dietética pode proporcionar menor excreção de elementos nocivos ao meio ambiente, tais como N e o P (Esteves et al., 2019). A redução proteica promove o melhor aproveitamento do N e, consequentemente, sua menor excreção. A amônia ($NH_3$) emitida a partir dos dejetos é formada através da quebra da ureia presente na urina catalisada pela urease presente nas fezes, portanto a menor excreção de N também reduz a emissão de $NH_3$ (Sajeev et al., 2018). Em uma meta-análise realizada por Wang et al. (2020), conclui-se que a redução proteica foi responsável por diminuir a excreção de N e a emissão de $NH_3$ em 28,5 e 34,4%, respectivamente.

Devido a complexa cadeia de produção em que a suinocultura está inserida, a avaliação ambiental deve ser realizada de forma sistêmica, sendo que a análise de ciclo de vida (ACV) é uma ferramenta que pode ser utilizada para este tipo de avaliação. A ACV vem sendo utilizada para avaliar os impactos ambientais causados pela suinocultura, em que os experimentos buscam avaliar o impacto da utilização de alimentos alternativos, diferentes sistemas de criação, redução de PB, sistemas de manejo dos dejetos entre outros (Tallaksen et al., 2019; Monteiro et al., 2019; Dourmad et al., 2014; Nguyen et al., 2010). No entanto, ainda existem poucos estudos que avaliam o impacto ambiental da produção de suínos no Brasil, principalmente associados à estratégias nutricionais, a exemplo da redução da PB da dieta.

## 1. Conceitos sobre a proteína bruta, proteína ideal e exigência nutricional

Dietas formuladas utilizando-se a PB como referência apresentam excesso de muitos aminoácidos. Para que a exigência diária dos primeiros aminoácidos limitantes, em dietas para suínos, sejam supridas unicamente através dos alimentos, a proteína dietética deve ser elevada e, consequentemente, os demais aminoácidos apresentam uma concentração acima das exigências.

Dietas com alta proteína contém excesso de aminoácidos essenciais, promovendo maior excreção de N nas fezes e urina dos animais, devido a menor eficiência de utilização do N. A proteína em excesso também beneficia o desenvolvimento dos microrganismos patogênicos presentes no intestino grosso, o que pode causar lesões intestinais e o desenvolvimento de doenças (Wang et al., 2018).

Através de observações da composição aminoacídica de proteínas de alta qualidade e comparações da composição aminoacídica de tecidos corporais de suínos em crescimento, foi possível expressar a exigência ideal (proteína ideal) de aminoácidos. O pressuposto é que a proteína ideal é responsável por fornecer a quantidade de aminoácidos necessária para a mantença e produção. Portanto, o balanço ideal de aminoácidos pode variar de acordo com estado fisiológico e produtividade do animal (NRC, 2012).

Desta forma, dietas formuladas utilizando o conceito da proteína ideal tem como vantagem o fornecimento de aminoácidos o mais próximo da exigência diária do animal. Isso é realizado com a utilização de aminoácidos industriais (AAI) para que as necessidades aminoacídicas sejam supridas na dieta.

Para que o melhor aproveitamento dos nutrientes, assim como o melhor desempenho dos animais seja alcançado, é fundamental que a exigência diária do animal seja conhecida. Como dietas formuladas com redução proteica buscam atender as exigências dos animais sem que ocorram excessos de nutrientes, a subnutrição causada por uma definição errônea da exigência irá resultar em queda no desempenho, o mesmo é válido para as avaliações da composição nutricional dos alimentos utilizados nas dietas.

A digestibilidade ileal dos aminoácidos é a forma mais precisa de avaliação dos alimentos, pois após a passagem de proteínas e aminoácidos pelo intestino delgado, estes podem ser fermentados pela flora presente no intestino grosso, o que resultará em divergência na avaliação final da digestibilidade. A digestibilidade ileal pode ser expressa como digestibilidade ileal aparente, estandadizada e verdadeira. O ideal seria a utilização da digestibilidade ileal verdadeira nas avaliações, contudo essa é uma avaliação mais complexa, pois leva em conta as perdas endógenas basais e específicas (Stein et al., 2007).

Perdas endógenas específicas são dependentes da composição química do alimento e de fatores antinutricionais que podem estar presentes. Devido â maior complexidade em se determinar a perda endógena específica, a utilização da digestibilidade ileal estandardizada, que leva em conta apenas a perda endógena basal que não é influenciada pela composição do alimento, vem sendo utilizada na formulação de dietas (Stein et al., 2007).

O balanço ideal de aminoácidos na dieta é fundamental, pois quantidades inadequadas podem resultar em deficiência, toxicidade, antagonismo e imbalanço. Os primeiros sinais destes problemas serão observados através da queda no consumo e redução no crescimento (NRC, 2012). A toxicidade pode ser causada pelo consumo excessivo de algum aminoácido, e os mais tóxicos aos animais são os aminoácidos sulfurados (metionina e cisteina). Já o imbalanço ocorre quando qualquer aminoácido é fornecido acima da exigência nutricional (NRC 2012).

O antagonismo pode ocorrer entre aminoácidos que possuem estruturas químicas semelhantes, como os aminoácidos de cadeia ramificada (leucina, isoleucina e valina), que competem pelos sítios de absorção e também compartilham enzimas no metabolismo, tais como a aminotransferase de aminoácidos de cadeia ramificada. A leucina é responsável ainda por aumentar o catabolismo da valina e isoleucina, o que pode indisponibilzar estes aminoácidos para a síntese de novas proteínas e causar queda no crescimento devido a grande importância destes para a síntese de proteínas musculares. Leucina, isoleucina e valina representam aproximadamente 35% dos aminoácidos presentes nas proteínas musculares (Harper et al., 1984).

O excesso de leucina na dieta de suínos em crescimento é responsável por diminuir o consumo e prejudicar a retenção do nitrogênio. Esses efeitos resultam provavelmente do maior catabolismo da isoleucina e valina que, por sua vez, reduz a disponibilidade destes aminoácidos para a síntese proteica e também pela menor quantidade de triptofano que atravessa a barreira hematoencefálica, prejudicando a síntese de serotonina hipotalâmica (Know et al., 2019).

## 2. Redução proteica em rações para suínos, e a relação entre aminoácidos essenciais e não essenciais

A redução da PB na dieta de suínos pode ser realizada se a demanda dietética de aminoácidos essenciais for atendida com a utilização de AAI, quando necessário. Desta forma é possível melhorar a eficiência de utilização do N (Gloaguen et al., 2014).

Lisina, treonina, metionina e triptofano são os primeiros aminoácidos limitantes em dietas formuladas à base de milho e farelo de soja, e sua deficiência deve ser suprida para que o desempenho dos animais não seja prejudicado. No entanto, Figueroa et al. (2002) relataram que, ao se reduzir a PB dietética, a valina e isoleucina podem ser os próximos aminoácidos a limitar o desenvolvimento dos animais, se não forem suplementados na dieta.

Mesmo com a suplementação de AAI, ao reduzir a PB na dieta, os animais podem apresentar queda no desempenho, Gloaguen et al. (2014) concluíram que, além da suplementação de AAI, quando a redução na PB é acentuada, outro ponto que deve ser observado é  a quantidade de N presente na dieta. Uma redução acentuada na PB dietética pode causar a falta de nitrogênio não específico, que é utilizado na síntese de aminoácidos considerados não essenciais e, com isso, a síntese destes aminoácidos é comprometida e, consequentemente, o desempenho dos animais é prejudicado.

Os autores supracitados identificaram ainda que, em dietas à base de cereais e farelo de soja, após atender às exigências de lisina, treonina, metionina e triptofano, a sequência de aminoácidos que pode limitar o desempenho dos animais pode ser: valina, histidina, isoleucina, fenilalanina + tirosina posteriormente o N e a arginina. Isso demonstra a importância do nitrogênio não específico para a síntese de aminoácidos não essenciais.

A maior disponibilidade de AAI promove redução na inclusão proteica nas dietas de suínos, isso pode ser observado nas tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais (Rostagno et al., 2011; Rostagno et al., 2017) sendo que a recomendação proteica para suínos machos (30-50) castrados de alto potencial genético passou de 18,25 para 17,01%, mas a exigência de aminoácidos digestíveis teve comportamento oposto, já que aumentaram (Tabela 1).

O NRC (2012) não apresenta uma recomendação da PB dietética, pois esta versão apresenta apenas a recomendação de N total, mas se o coeficiente de 6,25% for utilizado para determinar a recomendação proteica dos valores propostos pelo NRC

(2012), será observada a tendência de redução de 2 a 4% na PB, quando comparado a edição anterior (Wang et al., 2018).

**Tabela 1**. Exigências nutricionais de suínos machos castrados de alto potencial genético com desempenho superior, em diferentes períodos

| | **2011*** | **2017**** | **Diferença percentual** |
|---|---|---|---|
| Proteína % | 18,25 | 17,01 | - 6,79 |
| Lisina dig % | 0,943 | 1,069 | + 13,36 |
| Metionina dig % | 0,283 | 0,321 | + 13,42 |
| Treonina dig % | 0,613 | 0,695 | + 13,37 |
| Triptofano dig % | 0,170 | 0,214 | + 25,88 |
| Valina dig % | 0,651 | 0,738 | + 13,36 |
| Isoleucina dig % | 0,519 | 0,588 | + 13,29 |
| Leucina dig % | 0,943 | 1,069 | + 13,36 |

*Rostagno et al. (2011), **Rostagno et al. (2017)

Com o desenvolvimento da indústria e a maior disponibilidade de aminoácidos como a valina e isoleucina, as recomendações proteicas em tabelas que ainda serão propostas poderão ser ainda mais baixas (Wang et al., 2018).

A redução da PB dietética e o aumento da inclusão de AAI às rações promovem uma mudança na relação entre o N provindo dos aminoácidos essenciais e o N provindo dos aminoácidos não essenciais. Com a diminuição da PB, a relação tende a ser maior para o N dos aminoácidos essenciais, pois o aporte dos aminoácidos essenciais provenientes dos alimentos é menor, mas sua correção é feita com a adição de AAI. Segundo Lenis et al. (1999), a relação de 50:50 entre o N essencial e N não essencial seria a mais adequada para a melhor retenção e utilização do N, e essa relação tem maior importância em dietas com redução de PB.

Rações que proporcionem a maior parte do N através de aminoácidos essenciais podem limitar o desempenho dos animais, visto que, embora a quantidade de N presente a ração seja alta, os animais podem apresentar baixa utilização na conversão do N presente nos aminoácidos essenciais, limitando, assim, a síntese de aminoácidos não essenciais (D´Mello, 2003).

## 3. Efeito da redução de proteína bruta sobre o desempenho, características de carcaça e qualidade de carne

Existem muitos questionamentos se a redução da proteína bruta da dieta pode prejudicar o desempenho dos animais. Conforme mencionado nesta revisão, a suplementação não é garantia que os aminoácidos estejam suprindo a demanda necessária, já que a redução proteica pode potencializar o antagonismo entre aminoácidos, alterar a relação entre aminoácidos essenciais e não essenciais, e até, mesmo limitar a quantidade de N não específico.

A elevada redução proteica exige que aminoácidos que não são comumente utilizados em dietas, tais como a valina e isoleucina também sejam suplementados. Trabalhos que utilizam redução proteica acentuada (até 6%) comprovam este fato. He et al. (2016) e Li et al. (2018) avaliaram a redução proteica para suínos em crescimento e terminação, e obtiveram resultados semelhantes, já que tanto os animais em crescimento quanto os que estavam em fase de terminação, apresentaram queda no desempenho. Como os autores suplementaram apenas lisina, metionina, triptofano e treonina, as dietas provavelmente apresentaram deficiência de um ou mais aminoácidos essenciais, limitando a síntese proteica e o desempenho dos animais.

Quando a redução de PB dietética é realizada de forma moderada (até 4%), não são observadas diferenças para as variáveis ganho de peso e conversão alimentar (Wang et al., 2020). O desempenho de animais na fase de creche (menos de 25 kg) é mais afetado por dietas com redução proteica que o desempenho de animais em fase de crescimento e terminação (Wang et al., 2020). Segundo Zhao et al. (2019), a redução da PB da dieta até 4% não prejudica o desempenho de suínos em crescimento e terminação quando a exigência dos aminoácidos essenciais é suprida, contudo os autores concluíram que a redução proteica é responsável por promover alterações na ordem de limitância dos aminoácidos essenciais, uma vez que em dietas para suínos (25 – 50 kg) a valina é o quinto aminoácido limitante, já em dietas para suínos (75 – 100 kg) a isoleucina é o quinto aminoácido a limitar o desempenho dos animais.

Quando a redução proteica é realizada de forma moderada, e a suplementação aminoacídica atende as exigências diárias dos animais, é provável que o desempenho não seja prejudicado. A redução pode ser realizada tanto para animais na fase de creche (Monteiro et al., 2019), quanto para fase de terminação (Yamazaki et al., 2019) sem que o desempenho seja prejudicado.

A absorção de AAI ocorre de forma mais rápida que a de aminoácidos ligados a proteínas provenientes dos alimentos (Yen et al., 2004). Desta forma, dietas com maior inclusão de AAI podem limitar o desempenho dos animais, por diferenças nas concentrações de aminoácidos plasmáticos na fase pós-prandial. Além de compor a parte estrutural das proteínas, os aminoácidos, juntamente com a insulina, promovem a síntese proteica através da modulação da atividade da mTOR (Wang et al., 2015), sendo assim, a pool de aminoácidos presentes no plasma é fundamental para a ativação de enzimas responsáveis pela síntese proteica, assim como, para a formação das cadeias polipeptídicas.

A redução da proteína pode ainda promover alteração nas características de carcaça e qualidade de carne. Segundo Li et al. (2018), a redução proteica foi responsável por aumentar a gordura intramuscular e diminuir a força de cisalhamento do músculo *longissimus dorsi*, além de aumentar a concentração de alanina, ácido glutâmico, tirosina e taurina livres no músculo. Com isso, os autores concluíram que a redução proteica foi responsável por promover a melhora na qualidade de carne de suínos em crescimento e terminação.

Assim como no experimento supracitado, Wang et al. (2019) observaram que a redução da PB resultou em alterações nas concentrações de alguns aminoácidos presentes no soro sanguíneo, a concentração de isoleucina e histidina diminuíram com a redução da PB da dieta de suínos em fase de crescimento e terminação. Neste experimento, os autores concluíram que em um ambiente com temperatura elevada (30 – 35 °C), os animais que receberam dietas com alta proteína e dietas com baixa proteína não apresentaram diferenças em relação ao desempenho. Porém, em um segundo experimento, os animais foram mantidos em temperatura amena (25 – 30 °C) e, neste ambiente, os animais que receberam dietas com baixa proteína apresentaram queda de desempenho, e em nenhum dos experimentos foram observadas diferenças em relação âs características de carcaça entre as dietas de alta e baixa proteína.

Como não houve diferença significativa no desempenho dos animais quando estes foram mantidos em temperatura elevada, Wang et al. (2019) concluíram que o ambiente (30 – 35 °C) foi responsável por restringir o desempenho dos animais, o que não ocorreu quando os animais foram alojados em ambiente com temperatura amena, desta vez o responsável pela restrição no desempenho seria a baixa proteína, já que os animais que receberam dietas com alta concentração proteica apresentaram melhor desempenho. Como já citado anteriormente, a concentração de aminoácidos no soro também apresentaram diferenças entre os tratamentos avaliados, uma vez que a redução da proteína promoveu queda na concentração da isoleucina e histidina e aumento na concentração de lisina no soro sanguíneo. Isso pode explicar a queda no desempenho dos animais mantidos em temperatura amena: as baixas concentrações de isoleucina e histidina disponíveis podem ter limitado a síntese proteica.

Apesar de não observarem diferenças em relação a peso da carcaça, espessura de toucinho, perda de água por gotejamento, Zhao et al. (2019) ressaltam que a redução da PB da dieta proporcionou redução no peso relativo do pâncreas e dos rins. Segundo os autores a redução no peso relativo destes órgãos está relacionada â menor atividade metabólica em suínos alimentados com dietas de menor concentração proteica, dado que o pâncreas e os rins são fundamentais nos processos de digestão e metabolismo das proteínas. O pâncreas é responsável pela produção e secreção de enzimas que atuam na hidrólise das proteínas em peptídeos e aminoácidos e os rins são fundamentais para a excreção do N (Zhao et al., 2019).

## 4. Redução da excreção de nutrientes por meio da utilização de dietas multifases

A ingestão adequada de aminoácidos essenciais é dependente dos alimentos utilizados nas dietas. Alimentos que contenham um padrão de aminoácidos desejável para atender às necessidades de mantença e produção em cada fase de desenvolvimento dos suínos são fundamentais, caso o objetivo da dieta seja a redução da excreção de nutrientes. O uso de AAI possibilita a redução da PB dietética, além de auxiliar no adequado fornecimento diário de aminoácidos e redução dos gastos metabólicos com deaminação e excreção de ureia (NRC 2012).

A excreção do N em excesso é uma resposta fisiológica do animal, já que, diferentemente dos lipídeos e outros nutrientes, os aminoácidos que excedem as necessidades diárias dos animais não podem ser armazenados como tal, e sua excreção é feita principalmente através da urina (figura 1).

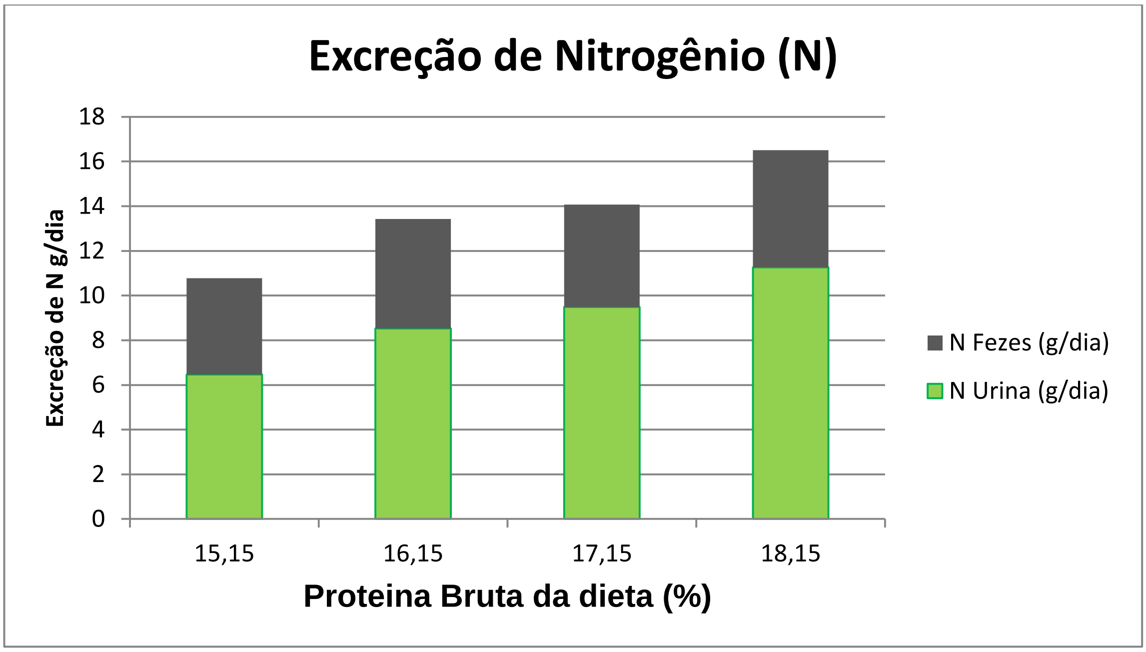


**Figura 1**. Nitrogênio excretado através das fezes e urina de suínos em crescimento (30-50 kg) alimentados com dietas contendo 15,15; 16,15; 17,15 e 18,15% de proteína bruta (Esteves et al., 2019).

Aliada à redução proteica, o ajuste adequado entre a exigência e o fornecimento diário de nutrientes ao animal promovem o melhor aproveitamento de nutrientes, tais como o N e o P. O melhor ajuste de dietas multifases é proveniente do fornecimento de nutrientes o mais próximo da exigência diária dos animais, prevenindo as deficiências e excessos que podem ocorrer durante o processo de produção (figura 2).

Através de uma simulação realizada com o auxílio do programa InraPorc, para suínos em crescimento e terminação, foi possível observar que a retenção de N aumentou de 32%, em um programa de alimentação de duas fases e sem inclusão de AAI a dieta, para 47% quando se forneceu rações que atenderam a exigência diária do animal e foi realizada a inclusão de AAI. O mesmo padrão foi observado em relação â retenção de P, que passou de 37% para 42% em dietas de duas fases sem inclusão de AAI para dietas que utilizavam a inclusão de AAI e as exigências eram determinadas diariamente (Monteiro et al., 2016).

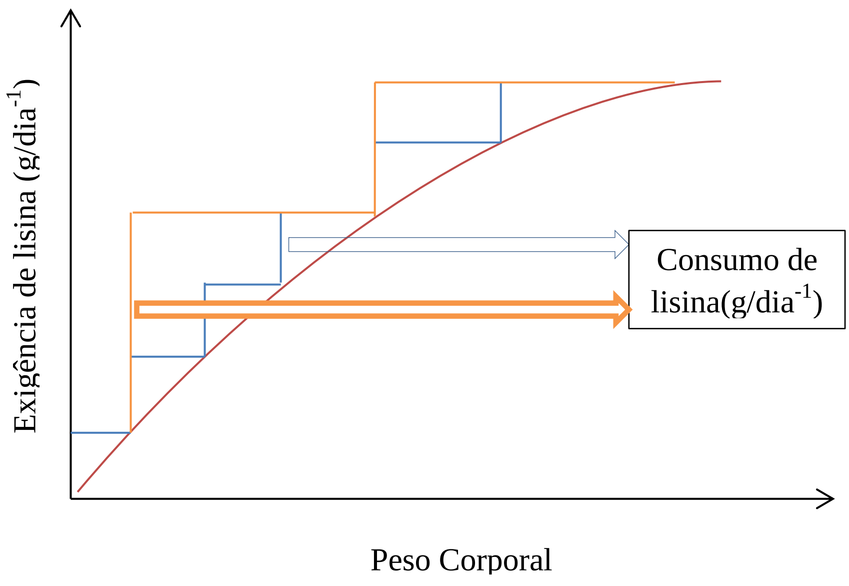


**Figura 2.** Dietas multifases podem promover o melhor ajuste entre a exigência diária do animal e o consumo diário do nutriente. No gráfico é possível observar a diferença entre o consumo de lisina em g/dia$^{-1}$ quando são fornecidas duas ou varias dietas ao longo da fase de crescimento e terminação de um suíno.

O melhor aproveitamento da dieta em programas alimentares multifaces e de precisão ocorre em decorrência da redução dos excessos, os nutrientes são fornecidos de forma a atender a necessidade do animal. Sistemas com várias dietas durante a fase de crescimento e terminação acabam por reduzir a oferta de nutrientes aos animais, com isso a correta determinação da exigência e da quantidade de nutrientes ofertada é crítica para o sucesso, visto que uma sub-oferta resultará em baixo desempenho dos animais. Se a quantidade fornecida for adequada, não haverá queda no desempenho e a excreção de nutrientes será reduzida. Segundo Andretta et al. (2014), a redução é de até 8,4% na excreção de nitrogênio para cada por cento de redução na proteína bruta, Monteiro et al. (2016) observaram uma redução de 9,0% a cada por cento de redução na proteína bruta.

## 5. Análise de ciclo de vida

A conscientização da importância na conservação dos recursos naturais e os possíveis impactos causados pela produção, consumo e disposição final de produtos evidenciam a necessidade de ferramentas que possam avaliar a cadeia de produção de forma sistêmica. A Análise de Ciclo de Vida (ACV) é uma técnica desenvolvida para este tipo de avaliação, sendo possível, identificar pontos críticos da produção e adotar técnicas mais eficientes, mitigando os impactos ambientais que podem ser gerados (ISO, 2006). Sistemas com o objetivo de melhorar a performance ambiental dos produtos devem conhecer e avaliar continuamente a produção.

A ACV é uma ferramenta utilizada para avaliar os impactos ambientais causados pela produção em todas as etapas da produção, desde a extração da matéria prima até o uso, descarte, reuso, reciclagem e disposição final do produto. Os impactos ambientais incluem a extração de recursos naturais a emissão de substâncias nocivas ao ambiente e também o uso da terra (Guinee et al., 2002).

A ACV é uma avaliação de natureza holística, essa característica é o que possibilita sua aplicação em cadeias de produção complexas, porém isso também resulta em limitações. A avaliação completa do ciclo de vida de um produto só pode ser alcançada através da simplificação de aspectos ocorridos ao longo do processo produtivo. Para que o desenvolvimento da avaliação seja possível, algumas decisões e suposições técnicas devem ser implementadas, e estas decisões e suposição devem ser claramente descritas no desenvolvimento da ACV (Guinne et al., 2002).

A avaliação de forma integrada do sistema de produção de suínos é muito importante. Quando se tem por objetivo melhorar o perfil ambiental de algum produto, que possui uma cadeia de produção complexa, é fundamental observar que a redução do impacto ambiental em uma etapa específica da produção não seja alocada para outra fase da produção. Um exemplo disso, na cadeia de produção de suínos, é que mudanças na composição das dietas podem resultar em menor excreção de elementos nocivos ao ambiente através dos dejetos dos animais, mas se essa mudança resultar em queda no desempenho, possivelmente o benefício da menor excreção dos elementos possa ser nulo quando considerarmos que os animais vão demorar mais dias até chegar ao peso médio de abate (Bandekar et al., 2019). A avaliação sistêmica da cadeia de produção poderá avaliar se a mudança foi benéfica ambientalmente.

Em decorrência da complexa cadeia de produção em que a suinocultura está envolvida (produção de grãos, transporte de produtos e rações, produção animal, manejo de dejetos, abate e distribuição de produtos de origem animal ao varejo, entre outros) existe a necessidade de uma ferramenta capaz de realizar uma avaliação sistêmica para que conclusões possam ser obtidas (Figura 3). Em relação às questões ambientais, a ACV é uma ferramenta eficaz para esta avaliação (Reckmann and Krieter 2013).


**Figura 3.** Análise de ciclo de vida da cadeia de produção de suínos

Com a produção de um inventário que quantifique as entradas e saídas de um sistema, e a avaliação dos impactos ambientais causados por esses fluxos, é possível identificar oportunidades que melhorem o sistema e promovam menor impacto, propor estratégias que priorizem determinados sistemas de produção auxiliando na tomada de decisões de empresas, organizações governamentais e não governamentais. Através da seleção de indicadores eficientes é oportuno a promoção do produto no mercado, enfatizando a preocupação ambiental em sua produção (ISO, 1997).

Na ACV, é fundamental que os dados sejam apresentados de forma clara e precisa, visto que a exatidão do estudo é dependente dos dados que estão sendo utilizados. Assim como outras técnicas, existem limitações a serem abordadas, sendo, então, essencial que o sistema avaliado, a coleta de dados, os modelos utilizados na avaliação dos impactos e as lacunas observadas no estudo sejam discutidos de forma clara. A comparação de resultados de diferentes avaliações só é possível quando estas apresentarem a mesma abordagem (ISO, 1997).

### 5.1. Estrutura utilizada para desenvolver um estudo de análise de ciclo de vida

Não existe uma estrutura pré-definida para o desenvolvimento de uma ACV, já que o estudo é dependente do sistema a ser avaliado, contudo, quatro etapas para o desenvolvimento são obrigatórias: definição do objetivo e do escopo, análise do inventário, avaliação do impacto do ciclo de vida e interpretação dos resultados (Figura 4). Existem casos onde a análise e interpretação do inventário é suficiente para elucidar o objeto da análise de ciclo de vida, neste caso o trabalho é denominado estudo de inventário de ciclo de vida (estudos de ICV), em que, a etapa de avaliação do impacto de ciclo de vida é ausente (ISO, 2006).

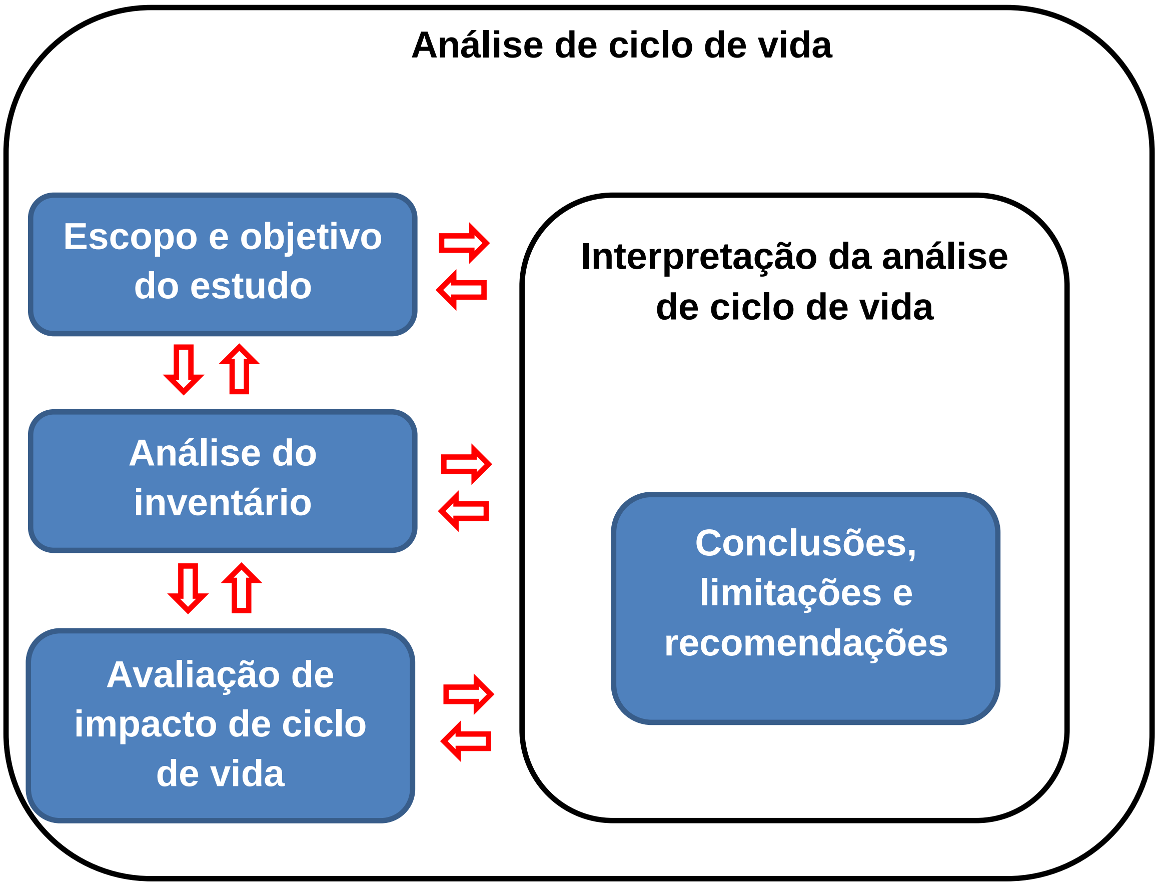


**Figura 4.** Estrutura de analise de ciclo de vida (ISO, 2006)

### 5.2. Definição do objetivo e escopo do estudo

O objetivo deve deixar claro o que se pretende com o desenvolvimento do estudo e qual o público alvo do trabalho. No escopo deve ser descrito o sistema de produção, quais etapas do sistema serão avaliadas, unidade funcional, seleção das categorias de impacto, os processos de alocação que serão utilizados e limitações do estudo. O principal propósito da unidade funcional é esclarecer a qual produto os impactos estão sendo relacionados. (IPCC, 2006).

Não existe consenso sobre a escolha da unidade funcional que deve ser utilizada em ACV na suinocultura. Na literatura pode ser observada certa diversidade nas escolhas o que acarretam em repostas divergentes entre os sistemas produtivos. Existem estudos capazes de elucidar questões referentes ao antagonismo na escolha de unidades funcionais. Isso pode ser observado quando as unidade utilizadas se referem à produção de alimentos, como o impacto referente a produção de um kg de carne, e â preservação da terra, como o uso da terra por hectare.

O grau de intensificação da produção é inversamente proporcional aos impactos obtidos quando são expressos por kg de carne produzida, mas quando a unidade funcional é expressa, como uso da terra por hectare, quanto maior a intensificação de produção do sistema maiores serão os impactos observados. Dourmad et al. (2014) avaliando diferentes sistemas de produção para suínos, entre eles o sistema convencional (intensivo) e o tradicional (extensivo), concluíram que quando a unidade funcional foi kg de carne produzida, os impactos do sistema intensivo de produção foram menores quando comparados ao sistema tradicional. Quando a unidade funcional utilizada foi o uso da terra por hectare, os impactos do sistema convencional foram maiores que os obtidos para o sistema tradicional.

### 5.3. Análise do inventário

A etapa de análise do inventário corresponde ao momento da coleta dos dados do processo que está sendo analisado. Neste momento, é realizada a quantificação do que é utilizado no sistema (inputs) e o que é produzido (outputs). O material utilizado pelo sistema pode ser um recurso natural, os produtos podem ser emissões lançadas ao ar, água e ao solo. A etapa de análise de inventário é um processo interativo, pois através das coletas de dados é possível adquirir maior conhecimento sobre o processo, sendo que novas questões possam ser levantadas a partir deste momento e ajustes no objetivo do trabalho possam ser necessários (ISO, 14040).

Em sistemas de produção, é comum que um ou mais produtos sejam obtidos ao final do processo, com isso existe a necessidade da aplicação de técnicas para a identificação da contribuição de cada produto no consumo de recursos e emissão de resíduos referentes ao processo (Nguyen et al., 2010). Para isso, pode-se expandir o sistema de produção, de forma que cada produto tenha seu sistema específico, contudo, quando isso não é possível, é necessário que seja realizada a alocação. A alocação pode ser realizada de acordo com as propriedades físicas (massa, energia) ou de acordo com o valor econômico dos produtos (ISO, 14040).

### 5.4. Avaliação do impacto de ciclo de vida

A avaliação do impacto de ciclo de vida (AICV) tem como finalidade avaliar a significância ambiental dos resultados do inventário por meio de modelos e fatores de caracterização contidos nos métodos de AICV (Mendes et al., 2013). A AICV deve ser planejada de forma a atender os objetivos e escopo do estudo.

Na etapa de AICV, as etapas obrigatórias são: a seleção das categorias de impacto, dos indicadores da categoria e a caracterização dos modelos; a ligação dos resultados do impacto de ciclo de vida as categorias de impacto selecionadas (classificação); e o cálculo dos resultados dos indicadores das categorias (caracterização) (Figura 5).

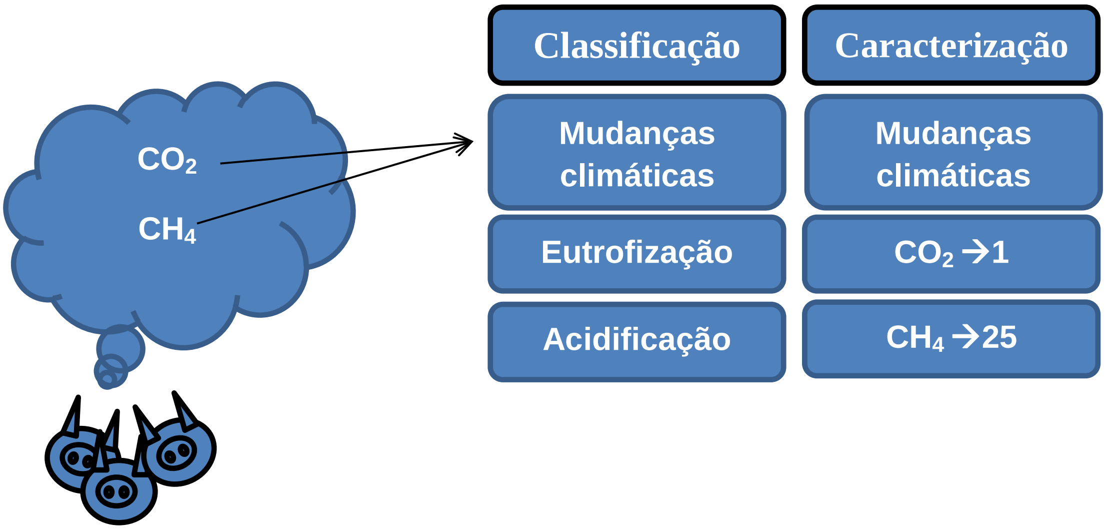


**Figura 5.** Avaliação do impacto de ciclo de vida

As categorias de impacto, os indicadores e os modelos de caracterização escolhidos devem ser justificados e consistentes com os objetivos e escopo da ACV. A análise impacto de ciclo de vida pode ser desenvolvida, utilizando-se métodos clássicos, a caracterização usa indicadores localizados ao longo da cadeia de causa e efeito, antes de chegar ao ponto final da categoria (*midpoint*) ou métodos orientados ao dano, a caracterização considera toda a cadeia até o seu ponto final, ex: saúde humana, ambiente natural ou recursos naturais (*endpoint*) (Guinné et al., 2002).

### 5.5. Interpretação do ciclo de vida

A fase de interpretação do ciclo de vida tem como propósito gerar recomendações e conclusões que sejam consistentes com o objetivo e escopo do estudo. Estas devem ser embasadas nas constatações da análise de inventário e da avaliação de impactos. A interpretação envolve ainda a análise crítica e revisão do escopo da ACV, assim como avaliação da qualidade (solidez e robustez) dos dados coletados.

### 5.6. Estudos de análise de ciclo de vida na suinocultura

Como grande parte dos impactos ambientais ocorridos durante o processo de produção de suínos é decorrente da etapa da produção de alimentos, muitos trabalhos buscam avaliar como a mudança na composição das dietas poderá impactar toda a cadeia de produção. A utilização de alimentos de baixo impacto ambiental às dietas podem trazer benefícios a toda cadeia de produção, porém o alimento deve ter características nutricionais desejáveis para que a digestibilidade dos nutrientes não seja afetada, comprometendo assim o desempenho dos animais.

Desta forma, Bandekar et al. (2019) relataram que manejos que resultam em queda no GPD podem proporcionar o aumento na emissão de gases de efeito estufa, pois quanto menor o GPD, mais tempo o animal leva para atingir o peso de abate, o que proporciona o maior consumo de alimentos e maior produção de dejetos. Os autores observaram que as etapas de manejo de dejetos e produção de alimentos foram as que mais contribuíram para emissão de gases responsáveis por mudanças climáticas.

Com o objetivo de avaliar o impacto da redução proteica para suínos em crescimento e terminação, Ogino et al. (2013) relataram que as etapas responsáveis pelos maiores impactos na emissão de gases de efeito estufa foram decorrentes da produção das dietas e manejo dos dejetos. Os autores concluem que a utilização de AAI foi responsável por reduzir a emissão de gases de efeito estufa e mitigar os impactos observados para acidificação e eutrofização, porém houve um leve aumento na demanda energética devido ao maior impacto observado nesta categoria para dietas com maior inclusão de AAI.

Outros estudos ressaltam a grande contribuição da produção das dietas nos impactos observados na cadeia de produção de suínos. Em estudo realizado para avaliar o impacto ambiental causado pela produção de suínos na Alemanha, sendo que o sistema de produção considerado abrangia as etapas de produção de alimentos, transporte, alojamento e procedimentos realizados no abate dos animais, os autores estimaram os impactos em 3,22 kg $CO_2$-eq; 23,3 g $PO_4$-eq e 57,1 g $SO_2$-eq por kg de carcaça, para as categorias de impacto aquecimento global, potencial de eutrofização e potencial de acidificação, respectivamente (Reckmann and Krieter 2013).

Os autores supracitados destacam que, para a categoria de aquecimento global, aproximadamente um terço dos impactos foram causados na etapa de alojamento dos animais, porém a etapa que mais impactou nesta categoria foi a de produção dos alimentos (62-69% dos impactos), sendo que 82% do $CO_2$ e 95% do $N_2O$ emitidos pelo sistema foram em decorrência da etapa de produção de alimentos. Em contraposição, 93% de todo o $CH_4$ emitido pelo sistema ocorreu na fase de alojamento dos animais. Resultado semelhante foi obtido para as emissões de $NH_3$, pois do total de 57,1 g $SO_2$-eq por kg de carcaça, para a categoria potencial de acidificação, 87% foi emitido durante o processo de alojamento dos animais.

Com o objetivo de avaliar o impacto ambiental em diferentes cenários de produção (alimentação convencional; melhor eficiência alimentar do rebanho; diminuição no tempo de estoque dos dejetos; utilização dos dejetos para geração de energia ou a união de melhor eficiência alimentar, diminuição no tempo de estoque dos dejetos e utilização dos dejetos para geração de energia) Nguyen et al. (2010) concluíram que a implementação de todas as melhorias acima propostas proporcionaram o melhor resultado, reduzindo até 61% no consumo de combustíveis fósseis e 49% na emissão de gases de efeito estufa. A utilização de dejetos para produção de energia e a melhor eficiência alimentar foram os métodos que proporcionaram maior redução no uso de combustíveis fósseis, 74,4% e 24,5%, respectivamente. Em relação às emissões de gases de efeito estufa, os autores encontraram resultados semelhantes, sendo que a utilização de dejetos para produção de energia obteve a maior contribuição na redução das emissões de gases de efeito estufa (redução de 47%), seguida pela melhor eficiência alimentar (28%) e menor tempo de estoque dos dejetos (26%).

Contudo, os autores demonstram que quando o uso da terra é considerado no cálculo, uma constante de 1,9 kg $CO_2/m^2$ ano é utilizada na correção dos impactos causados pela produção dos alimentos utilizados na ração, visto que áreas não desmatadas são responsáveis pelo sequestro de carbono, o que não ocorre quando estas dão lugar ao cultivo de grãos. Portanto, quando esse aspecto é considerado no cálculo, a melhor eficiência alimentar torna-se a alternativa mais eficiente na redução da emissão de gases de efeito estufa.

Diferenças relativas ao impacto causado pela produção de grãos em áreas recentemente desmatadas também podem levar a conclusões distintas quanto a eficiência da inclusão de AAI a dietas de suínos em crescimento e terminação. Com o objetivo de avaliar o impacto ambiental de rações que utilizaram grãos cultivados na região centro-oeste (áreas recentemente desmatadas) ou região sul do Brasil, pode-se observar que a inclusão de AAI é eficiente em reduzir as emissões de $CO_2$-eq e capaz de mitigar os impactos da produção de suínos para a categoria referente a mudanças climáticas, quando os animais foram alimentados utilizando-se as rações produzidas com a soja cultivado na região centro-oeste do Brasil. Porém, quando se utilizou a soja cultivada na região sul, a inclusão de AAI não foi tão eficaz em reduzir os impactos para esta categoria (Monteiro et al., 2016).

Estudos que proporcionem resultados do impacto ambiental da produção animal são fundamentais, uma vez que a demanda de produtos de origem animal será intensificada nas próximas décadas. Desta forma, avaliações que auxiliem na tomada de decisões são indispensáveis e poucos trabalhos de ACV da produção de suínos foram realizados no Brasil, e, devido à importância do país no mercado mundial de carne suína (ABPA, 2018), esta linha de pesquisa tem grande potencial para ser explorada.

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# II-OBJETIVOS GERAIS

Quantificar a excreção de nitrogênio e fósforo dos suínos na fase de crescimento I (30-50 kg) e crescimento II (50-70 kg), assim como o desempenho dos animais nestas fases, recebendo dietas com níveis decrescentes de proteína bruta, e utilizar estes dados nos cálculos da análise do ciclo de vida da produção de suínos, dos 30 aos 50 e dos 50 aos 70 kg de peso vivo.

## III-The reduction of crude protein with the supplementation of amino acids in the diet reduces the environmental impacts of growing pig production evaluated through life cycle assessment

**Abstract:** The objective, based on studies of nitrogen balance and performance, was to use life cycle assessment (LCA) to assess the environmental impact of growing pigs fed diets with reduced crude protein (CP) and supplementation of industrial amino acids. Experiment I (nitrogen and phosphorus balance): 20 crossbred barrows with an average initial weight of 31.80 ± 2.39 kg were used, housed in metabolic cages and distributed in a randomized block design with four treatments, five replications and one animal per experimental unit. Experiment II (performance): 44 crossbred barrows, with an average initial weight of 30.10 ± 0.63 kg, were distributed in a randomized block design with four treatments and 11 replications, one animal per experimental unit. The treatments used in the two experiments consisted of four diets containing 18.15; 17.15; 16.15 and 15.15% CP, and supplementation of industrial amino acids so that the requirements of all digestible amino acids were met. The protein reduction resulted in the best daily weight gain (P = 0.011) and final weight (P = 0.020) of the animals, as well as a better use of N and P, which can be confirmed by the retained N (P = 0.003) and absorbed P (P = 0.017). There was a reduction in environmental impacts for some categories when dietary CP decreased from 18.15 to 15.15%, with a reduction for acidification potential from 35.34 to 31.58 g $SO_2$-eq (P = 0.015). A reduction was also observed for the eutrophication potential, from 11.90 to 10.31 g $PO_4$-eq (P = 0.001), just as the land occupation decreased from 2.15 to 1.89 $m^2$-year (P = 0.005), respectively. Although variations were observed for the categories GWP, CED and TE, there was no difference between the treatments evaluated (P> 0.05). It was concluded that the reduction of CP and supplementation of industrial amino acids in diets for growing pigs (30 - 50 kg) reduced the environmental impacts for the acidification, eutrophication and land occupation categories.

Keywords: acidification, amino acids, nitrogen.

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## 1. Introduction

The quantification of the environmental impacts caused by animal production is extremely important, because in this way it is possible to highlight the critical points of the production process and act in order to mitigate its effects. Life cycle assessment (LCA) is an effective tool for comparing products and identifying environmental impacts caused by them (Reckmann et al., 2013). In a complex production chain such as pigs, which involves grain production, transportation, feed manufacture, animal production, among others, LCA allows systemic analysis and identification of critical points of production (Dourmad et al., 2014). In this sense, LCA has already been used to quantify the environmental impact of pig production in several countries, such as Australia (Wiedeman et al., 2018), Canada (Mackenzie et al., 2016), Cuba (Reyes et al., 2019), Italy (Bava et al., 2017), among others.

Much of the environmental impact caused by pig production occurs during the growing period of the ingredients used in the production of the feed (Dourmad et al., 2014; Monteiro et al., 2019). However, due to the large amount of manure generated in the animal production stage and the potential impact on air, water and soil, this stage has been the focus of public discussions. The problem is that manure generated in the production stage, such as nitrogen (N), phosphorus (P) and zinc (Zn) can cause acidification, eutrophication and ecotoxicity of the environment. Thus, changes in the nutritional composition of the feed can lead to significant differences in the environmental impact caused by the production of pigs, since they will affect the inclusion of ingredients and, consequently, the demand for their production, as well as the digestibility of nutrients, such as N and P (He et al., 2016; Monteiro et al., 2019).

The reduction in CP levels and the supplementation of industrial amino acids in diets provide the best balance between daily requirement of amino acids and daily consumption by the animal. This can provide the best use of some amino acids and, consequently, reduce the excretion of N (He et al., 2016). Allied to this, diets with an adequate balance of amino acids can provide a greater amount of net energy, since when in excess the amino acids cannot be stored, they need to be deaminated, which results in greater energy expenditure by metabolism.

Research with the aim of assessing the environmental impact of swine production using LCA has already been carried out, but is still under development in

Brazil. However, efforts have been made to evaluate specific stages of production. Another question of great relevance is that to obtain the data for this study, a metabolism experiment was carried out to evaluate the digestibility of nutrients present in the diets and a second experiment to evaluate the performance of the animals. Experiments with similar objectives to those proposed in the present study have already been carried out by Reckmann et al. (2016) and Monteiro et al. (2019). In the first work, the authors assumed that protein reduction does not influence the performance of animals, since nutritional requirements were met in all diets. In the second work, the digestibility and performance of the animals were evaluated, however, the authors quantified the impacts for animals in a different phase from the proposal in the present study.

Due to the complexity of the digestive and metabolic processes, as well as the difficulty in controlling some factors such as the relationship between essential and non-essential amino acids with the protein reduction of the diet, even when the nutritional requirement is met, it is essential that the evaluation of digestibility and the performance of the animals is performed, providing greater clarity of the results obtained. Therefore, the objective of this work was to evaluate the environmental impact, through life cycle assessment, of diets with reduction of crude protein and supplementation of industrial amino acids for crossbred barrows in the growth phase (30-50 kg).

## 2. Materials and methods

### 2.1 Goal and scope

This study was carried out at the State University of Maringá (UEM) which is located in the northwest region of Paraná, a state of great representativeness in pig production in Brazil. The objective was to evaluate the environmental impact of diets with reduction of crude protein and supplementation of industrial amino acids for crossbred barrows in the growth phase (30-50 kg) and to generate information that can be used by the pig industry, researchers and society in the search for sustainability of the productive system.

### 2.2 Description of the system

Two experiments were carried out to perform the LCA. Experiment I: digestibility of four diets with protein reduction, to assess the use of nutrients and account for the excretion of manure (feces and urine). Experiment II: performance, plasma urea, backfat thickness and depth of the *longissimus lumborum* muscle of animals that received the same diets used in experiment I. The complete description of the experiments is performed in items 2.10 and 2.11.

### 2.3 System and functional unit limits

In order to perform the LCA, the stages of animal production, cultivation, drying and processing of grains, transportation of ingredients to the factory and from the factory to the farm, production of feed, storage, transport and application of manure to the soil were considered. The impacts were considered at a specific stage (30–50 kg), so the impacts related to the process of transport and slaughter of the animals were not evaluated. According to Reckmann et al. (2013), the slaughter process has a low environmental impact when compared to the stages of feed production and animal production, representing only 1 and 8% of the total impacts for categories such as acidification and eutrophication potential, respectively.

Although the use of the area necessary for the construction of the facilities has not been used in the analysis, the area necessary for the production of grains has been accounted for in the system. The manure generated during the animals' housing phase was accounted for and used as a source of N, P and K in the fertilization of crops, reducing the use of chemical fertilizers. The equivalence factor (EF) used for N was 75%, assuming an extra loss of 5% in the form of nitrate (Garcia-Launay et al., 2014; Nguyen et al., 2010). For the P and K present in the manure, the EF used was 100% (Sommer et al., 2008). All impacts related to manure management, including storage and application, have been allocated and accounted for. The functional unit was one kg of live weight gain (LWG) in the growth phase 30-50 kg. The definition of the system limits is shown in figure 1, and is based on Nguyen et al. (2010).

### 2.4 Life cycle inventory

The resources used and the emissions associated with the production and transport of raw materials for grain production were obtained through the Ecoinvent version 3 database (SimaPro LCA software 8.0, Pré Consultants). The use of electric energy for lighting and ventilation of the warehouses was considered, however, the emissions and resources used for the construction of the facilities, vaccines, veterinary drugs, detergents and disinfectants used to clean the facilities were not evaluated (Arrieta and González, 2019).

### 2.5 Grain Production

As the second largest producer of soybeans, behind only the midwest region, it was assumed that the soybeans used were produced in the southern region of Brazil (CONAB, 2017). The inventory for soy cultivation was based on Silva et al. (2010), with an economic allocation being made to determine the impacts related to oil and soybean meal (Garcia-Launay et al., 2014). The allocation is the partition of environmental impacts between different co-products, and can be carried out based on physical characteristics (mass and energy) or other factors, such as economic (Arrieta and González, 2019). The inventory for maize cultivation was based on Avarenga et al. (2012).

**→Inserir figura 1**

### 2.6 Uncultivated raw materials

The inventories for salt, dicalcium phosphate, sodium bicarbonate, limestone and premix were obtained from Wilfart et al. (2016). For the production of antioxidants and growth promoters, the same demand for resources and energy required for the production of premix was considered. For the production of the amino acids L-lysine HCl, DL-methionine and L-threonine, the inventory was obtained through Mosnier et al. (2011) that consider chemical and biological processes in the synthesis of these products. For the production of L-tryptophan L-valine and L-isoleucine, the demand for resources and energy was twice as high as for the production of L-lysine (Garcia-Launay et al., 2014).

### 2.7 Transport specifications

For the transportation of food and feed, the methodology proposed by Silva et al. (2010). For the transportation of imported products, transportation was initially established by sea and later by road. Given the importance of the southern region of Brazil in pig production, responsible for approximately 69% of the total number of animals slaughtered in the country (ABPA 2018), grain production was considered in the main producing centers of this region, as well as the region where the farm was located.

### 2.8 Feed formulation and production

The treatments consisted of four diets with decreasing levels of CP. The levels used were 18.15; 17.15; 16.15 and 15.15% CP (Table 1), with the requirements for digestible amino acids proposed by Rostagno et al. (2017) were met with the use of the amino acids L-lysine, DL-methionine, L-threonine, L-tryptophan, L-valine and L-isoleucine. The amino acid composition of corn and soybean meal was determined at Evonik Industries. For the calculation of digestible amino acids present in food and industrial amino acids, the digestibility coefficients proposed by Rostagno et al. (2017). Sodium bicarbonate was used to control the electrolyte balance of the diets.

The amino acids lysine, methionine, threonine, tryptophan, valine, isoleucine, arginine, leucine, phenylalanine and histidine were considered essential amino acids in the calculation of the relationship between essential amino acids (AAE): non-essential amino acids (AANE). For this calculation, the total concentration of each of these amino acids was considered, as well as the amount of N present in its composition. The N values used were those proposed by Rostagno et al. (2017). The N for the AANE was obtained through the difference between the total N of the diets and the N present in the AAE, adapted from Toledo et al. (2014).

The data referring to the production process of the rations were based on those proposed by Garcia-launay et al. (2014).

### 2.9 Animal production

The procedures performed in experiments I and II were approved by the Animal Use Ethics Committee of the State University of Maringá (CEUA n° 2846260819).

### 2.10 Experiment I: Metabolism

Twenty crossbred barrows, with an average initial weight of 31.80 ± 2.39 kg, were housed in metabolic cages, distributed in a randomized block design, with four treatments and five replications, one animal per experimental unit.

The amount of feed provided daily was calculated based on the metabolic weight (kg 0.75) and the average consumption recorded during the adaptation period. To avoid waste and facilitate ingestion, the rations were moistened with water, in approximately 30% of the ration, and supplied twice a day (7:30 am and 3:30 pm). After each meal, water was supplied in the feeder in the proportion of 3 mL of water / g of feed, to avoid excessive water consumption.

To determine the period of beginning and end of the collection of feces, 2% ferric oxide ($Fe_2O_3$) was added to the diets. The feces were collected daily and placed in plastic bags and stored in a freezer (-18 ° C), for later analysis. The urine was filtered and collected daily in plastic buckets containing 20 mL of HCl 1: 1, to avoid nitrogen volatilization and bacterial proliferation. Aliquots of 20% of the total volume were removed and packed in plastic bottles and frozen (-18 ° C).

## 2.11 2.11 Experiment 2: Performance

### 2.11.1 Performance

Forty four crossbred barrows with an average initial weight of 30.10 ± 0.63 kg were used. These were distributed in a randomized block design, with four treatments and 11 replications, one animal per experimental unit. The animals were weighed at the beginning and at the end of the experimental period to determine daily weight gain (DWG). The rations provided and leftovers were also weighed to calculate daily feed intake (DFI) and feed conversion rate (FCR).

### 2.11.2 *Longissimus lumborum* and backfat thickness

When the animals reached an average weight of 51.21 ± 2.83 kg, the backfat thickness (BT) and depth of the longissimus lumborum (LL) muscle were evaluated, using an equipment consisting of an ecocamera (Aloka® SSD- 500 Vet) coupled to a 14.5 cm and 3.5 MHz probe. For this measurement to be performed, the animals were previously shaved between the tenth and eleventh ribs. (Dutra Jr et al., 2001).

### 2.11.3 Plasma urea

At the end of the experiment, the animals were subjected to a 6-hour fast to collect blood. The samples were collected and transferred to a tube containing EDTA, and subsequently centrifuged at 3000 rpm for 15 minutes. The plasma was transferred to polyethylene microtubes and stored in a freezer. The urea analysis was performed by the colorimetric method, using a commercial kit, following the standard operating procedures described therein.

### 2.12 Laboratory analysis

The feed was analyzed according to the Association of Official Analytical Chemists - AOAC (2005), regarding the contents of dry matter (method 950.46), ash (method 942.05), crude fiber (method 962.09), nitrogen (method 984.13). The values of P, copper (Cu), Zn and K were obtained using a UV-Vis spectrophotometer. Urine N content was also assessed. In the feces, the contents of N, P, dry matter, ash and crude fiber were determined, following the same methodology used in the analysis of the diets.

### 2.13 Life cycle impact

#### 2.13.1 Emissions from pig production

Emissions were calculated for the stages of animal housing, storage and application of manure, as proposed by Monteiro et al. (2016). Through laboratory analysis, the amounts of N, P and excreted organic matter were obtained, for later determination of the amounts of each nutrient available for application.

The excretion of the minerals Cu, Zn and K were obtained using the equations proposed by Rigolot et al. (2010a). The $NH_3$ emissions resulting from the stages of accommodation and manure management were carried out considering the temperature of the shed, and were calculated according to the equations proposed by Rigolot et al. (2010b) and the IPCC (2006).

#### 2.13.2 Characterization factors

The LCA was based on the CML 2001 (baseline) version 3.02 method, implemented in Simapro version 8.05 (PRé Consultants), adding the following categories: land occupation from CML 2001 (all categories) version 2.04 and cumulative energy demand version 1.8 (non-renewable fossil + nuclear).

The characterization factors used to calculate the impact of growing pig production were: global warming potential (GWP, kg CO2-eq.), acidification potential

(AP, g SO2-eq.), eutrophication potential (EP, gPO4- eq), terrestrial ecotoxicity (TE, g 1,4-DCB-eq.), cumulative energy demand (CED, MJ-eq.) and land occupation (LO, m2-year). For the GWP category, the potential for global warming over a 100-year horizon was considered.

### 2.14 Interpretation and statistical analysis

The retention coefficients of N and P were obtained for each of the experimental diets. These coefficients were used to determine the amounts excreted of each element during the growth period, using data from the performance evaluation of the animals. The LCA calculations were evaluated for each animal, and according to the consumption and excretion data of the animals, the environmental profile of each system was constructed, with the aid of the SAS software (SAS Inst. Inc., Cary, NC).

The performance, excretion and environmental impact data were subjected to analysis of variance using the SAS GLM procedure. The statistical model included the treatment and block effect. The significant data were submitted to regression analysis. The degrees of freedom related to the CP levels were divided into polynomials. All analyzes were performed using SAS software version 9.2.

## 3. Results

### 3.1 Life cycle assessment of feed

The reduction in CP increased the environmental impact for the categories evaluated, except for LO (Table 2). The most relevant increase was observed for the categories GWP, AP and CED. When comparing the differences between the diet with the highest and lowest protein values, the increase observed for the categories mentioned is between 12 and 21%. The exception was in relation to the impact caused to the LO category, which was 7% lower when the diet went from 18.15 to 15.15% PB.

### 3.2 Metabolism and performance

A reduction in the total N ($P < 0.001$) and P ($P = 0.002$) excretion was observed in the animals that received the CP reduced diets (Table 3). The lower excretion is due to the greater retention of these elements. The retained N increased from 61.48 to 69.93% in the diet of 18.15 and 15.15% CP, respectively. Retained P increased from 49.39% in the diet with the highest protein content to 56.05% in the diet with the lowest

CP. The reduction in dietary CP also promoted a lower intake of N ($P < 0.001$) and P ($P = 0.004$).

Despite the lower intake of N and P by animals that received diets with protein reduction, no significant differences were observed for the variables feed conversion rate (FCR), daily feed intake (DFI) and depth of the *longissimus lumborum* muscle ($P > 0.05$) (Table 4). However, there was an increase in the final weight gain ($P = 0.020$) and in the daily weight gain (DWG) ($P = 0.011$) with the reduction of CP in the diet. An increase of 11% in the DWG was observed when comparing the values obtained between the highest level (1.034 kg) and the lowest protein level (1.150 kg).

### 3.3 Life cycle analysis of growing pig production

Although there was an increase for the impact categories evaluated in the feed production stage when reducing the CP of the diets, with the exception of the LO category, this behavior was not observed in relation to animal production (Table 5). Protein reduction resulted in less impact for the AP ($P = 0.015$), EP ($P = 0.001$) and LO ($P = 0.005$) categories, with no difference ($P > 0.05$) for the GWP, CED and TE categories. The animals that received the 15.15% CP diet reduced by 11%, 13% and 12% the impacts for categories AP, EP and LO, respectively, when compared to the animals that received the diet with the highest protein level.

## 4. Discussion

### 4.1 Feed

The greatest impact for categories AP and EP obtained for diets with a lower protein level was also observed in another study. Assessing the impact of different diets for growing pigs Reckmann et al. (2016) obtained an increase of 7% and 4% in the environmental impact for the categories AP and EP, respectively, when they compared a conventional diet and a diet with a greater inclusion of industrial amino acids and a lower protein level.

The smallest difference in AP between the diets with the highest and lowest protein levels observed by the aforementioned authors and in our study, may have occurred due to the ingredients used in the formulation of the diets. In the present work, diets were formulated using corn and soybean meal, in the work of Reckmann et al.

(2016) diets were formulated using wheat, barley and soybean meal. Protein reduction may also be the cause of this variation, however the aforementioned authors describe a 15% reduction in CP between the diets with the highest and lowest protein levels, so the evaluated reduction was close to that used in our experiment (16%).

**4.2 Metabolism and performance**

The higher excretion of N for animals that received diets with high levels of CP was also observed by Monteiro et al. (2019), in which the total excretion of N went from 8.22 g $d^{-1}$ to 5.84 g $d^{-1}$ in diets with 19% and 16% CP, respectively, although the authors evaluated the protein reduction for animals from 15 to 30 kg. This reduction in the excretion of N was 29%, whereas the reduction obtained in our work was 35%.

The retention and excretion of N (table 3) corroborate other studies already carried out in order to assess the impact of reducing CP for pigs (Ferreira et al., 2005; He et al., 2016; Toledo et al., 2014). The lower excretion of N may occur due to the better use of dietary amino acids in diets with protein reduction and supplemented with industrial amino acids. He et al. (2016) concluded that there are differences in the ileal digestibility of amino acids such as lysine, methionine, threonine, tryptophan, valine, among others, when the CP of the diet for growing pigs is reduced from 18% to 13%. In the same study, the authors highlighted that the ileal digestibility of lysine increased from 72% to 80% when compared to diets with higher and lower protein levels, respectively.

A reduction in the DWG of the animals that received diets with a lower protein level was observed by He et al. (2016). However, the authors did not add valine, isoleucine and other amino acids to the diets, which can compromise the animals' performance if they are deficient. The best weight gain observed for animals that received diets with a lower protein level (table 4), may have occurred as a result of meeting the daily requirement of all essential amino acids, since the failure to meet the requirements of some of these would result in worsening the performance.

Animal consumption is another fact that leads us to believe that amino acid requirements have been met, as there were no differences in consumption and feed conversion. Schiavon et al. (2018), observed that, under conditions of consumption ad libitum, providing a diet with a lower concentration of lysine, pigs were able to ingest a greater amount of food, which, consequently, alleviated the dietary deficiency of this amino acid, concluding that amino acid restriction can lead to increased feed intake.

Protein consumption above the requirements of pigs generally results in the highest concentration of urea in the blood plasma, due to the greater deamination of amino acids that exceed the animal's daily requirement. Remus et al. (2019) reported that higher protein utilization efficiency, obtained through precision feeding and, consequently, lower protein consumption, reduces the plasma urea concentration of growing pigs. On the other hand, Pasquetti et al. (2015) pointed out that an amino acid deficiency can also limit protein synthesis and increase deamination.

In our study, an increase in BT (P = 0.062) and a reduction in plasma urea (P = 0.085) was observed, as the levels of CP in the diets were reduced. The behavior observed for these variables is in line with the results observed in the metabolism experiment. The lower excretion of N corroborates with the lower concentration of plasma urea, as well as an increase in BT, due to the lower energy expenditure required in deaminating excess amino acids. The results obtained are in agreement with those of Schiavon et al. (2018), who observed higher nitrogen consumption and excretion in diets with a higher protein concentration, and also highlight that the protein reduction provided an increase in intramuscular fat in the *longissumus lumborum* muscle.

The better use of N with the increase in the relationship between AAE: AANE in diets corroborates the results obtained by Lenis et al. (1999), since in the work the authors concluded that there was a better use of N when the diet went from a relationship between AAE: ANEE from 38:62 to 50:50. However, the authors also emphasize that this relationship between AAE: AANE is more important when the reduction in total N of the diet.

### 4.3 LCA of animal production

For the GWP category, the results varied between 2.95 and 2.80 kg $CO^2$-eq / kg of LWG, higher than those obtained by Monteiro et al. (2019), which can be related to the worsening in feed conversion and the higher excretion of N in our experiment. Even higher results for this category were obtained by Bandekar et al. (2019), however, the authors used DDGS as the main protein source and presented results for LCA in different stages of creation (gestation, lactation, growth and termination), in addition to different managements performed in each phase, such as comparison between sows managed in cages or in groups, diets without the use of growth promoters, immunocastrated or surgically castrated animals and evaluation of the use of ractopamine.

In this context, Bandekar et al. (2019) reported that management that results in a reduction in the DWG can provide an increase in the emission of greenhouse gases, because the lower the DWG the longer the animal takes to reach the slaughter weight, which provides the highest food consumption and higher production of manure. As in our study, the authors observed that the stages of manure management and food production were the ones that most contributed to GWP (Figure 2).

Although the greater inclusion of amino acids increased AP, when considering the kg of feed produced (table 2), this result was not observed when considering the impact on animal production (table 5), since the impact obtained for the highest content protein content was 35.34 g $SO_2$-eq per LWG, however for the diet with greater inclusion of amino acids the value obtained was 31.58 g $SO_2$-eq per LWG. According to Reckmann et al. (2016), an efficient way to reduce the environmental impact of pig production is through the use of industrial amino acids in diets. The authors concluded that it was possible to reduce the impacts between 3 and 11% for the evaluated categories (GWP, AP, EP and LO) when compared to the results of a conventional diet.

The inclusion of industrial amino acids in diets is of great importance for AP, and as can be seen in the metabolism experiment, the lower protein concentration resulted in better utilization of N present in the diet and, consequently, provided less excretion of it to the environment. The total excretion of N decreased from 16.50 g $d^{-1}$ to 10.76 g $d^{-1}$ (Table 3). When analyzing the two experiments (metabolism and performance) it was possible to observe a reduction of 29% in the total N emission during the process of animal housing and manure management between the diets with higher and lower protein levels, a value close to the estimated one in relation to the emission of $NH_3$, since the diet with the lowest protein concentration reduced the emission of this gas by 29%.

$NH_3$ is a gas of great relevance to the process of environmental acidification and although the production of feed has been responsible for most of the impact for the AP category, the animal housing and manure management stage have relevant impacts for this category, precisely by the $NH_3$ emission (Basset-Mens and Van der Werf 2005; Reckmann et al., 2013). The lower excretion of N obtained for animals fed diets with a lower protein level may explain the significant reduction in the impact for AP.

For the EP category a reduction (P = 0.001) was observed from 11 to 10 g $PO_4$-eq per kg of LWG, for the animals that received diets containing 18.15 and 15.15% CP, respectively. As for AP, N is also responsible for causing the EP to environments. Another element that can cause eutrophication of the environment is P (Guinée et al., 2002). The protein reduction resulted in greater digestibility of the P present in the diet, this may have occurred due to the lower concentration of phytic phosphorus in the diets of lower protein value.

The lower inclusion of soybean meal provided a reduction in the concentration of phytic phosphorus, since soybean meal has a greater amount of phytic phosphorus (0.36%) in its composition in relation to the amount present in corn (0.18%) (Rostagno et al., 2017). Thus, the 15.15% CP diet has 8% less phytic phosphorus when compared to the 18.15% CP diet. The lower excretion of P and N caused less environmental impact per kg of LWG, even with the increase observed for the EP in relation to production per kg of feed.

The lower impact for the AP and EP categories, due to the protein reduction in the pigs' diet, has already been observed in other studies (Monteiro et al., 2016; Ogino et al., 2013). However, Monteiro et al. (2019) did not observe differences for these categories when assessing protein reduction for pigs in the daycare phase, which may be due to the animals having presented the same performance between the evaluated diets, a different result to that observed in the present study, since the reduction in CP in the diet provided improvement in the animals' weight gain and numerical reduction in FCR. This better weight gain may be related to the higher net energy of diets with reduced protein. Weight gain combined with better use of nutrients provided the reductions observed in relation to AP and EP.

The CED was not altered according to the CP levels evaluated and, as well as for AP, EP, TE and LO; feed production is the stage that most contributed to the impact of this category. Feed production represents 63% of the impacts observed for the CED category. The production of industrial amino acids requires a large amount of energy (Mosnier et al., 2011), thus, the inclusion of these amino acids in the diet caused an increase in CED for the production of diets with lower CP. In the evaluation of LCA related to animal production (kg of LWG) it is possible to observe that the feed production process has a greater contribution in the feed of 15.15% CP in relation to the 18.15% CP, due to the higher energy demand in the production of amino acids (Figure 2).

Although there was a difference of greater amplitude in relation to CED of the evaluated diets (kg of diet), the same was not observed in relation to animal production, which can be attributed to the better DWG of the animals that received the diets with lower concentration of CP. The high contribution of feed production to CED was also observed in other studies (Dourmad et al., 2014; Weidemann et al., 2018; Arrieta and González 2019; Monteiro et al., 2019). According to Weidemann et al. (2018), feed production had a significant contribution in relation to energy demand, the authors observed a variation in the contribution of this stage that varied from 59 to 72% between the evaluated systems.

In order to assess the impact of pig production in Argentina, Arrieta and González (2019) reported that the high energy demand was attributed to the production of food used in the production of feed, with the production of fertilizers representing 35% of this expenditure. One way to mitigate the energy demand is through the use of manure as fertilizers, in our study, we consider that part of the soil fertilization could be carried out through the available manure, thus it is possible to observe that the manure management has a negative effect on the CED (Figure 2).

As we do not consider the area required for the construction of the LCA facilities, practically every impact related to the LO category is related to grain production. Thus, it is possible to observe that the reduction of CP in the diet provided a reduction in the impact for the LO category, both regarding the production of one kg of feed and the impact for this category for one kg of LWG.

The reduction in impact with the lower inclusion of soybean meal occurs due to the larger area needed for soybean production in relation to the area needed for corn production. A similar result was observed by Garcia-Launay et al. (2014) who observed an increase of 19% in the area required for the production of soybean meal compared to that required for the production of corn, and the same trend was also observed by Monsier et al. (2011).

For the production of feed, the difference observed between the treatments of lower and higher protein value for LO was 7%, whereas the data obtained for LCA, regarding the impact observed on animal performance (one kg of LWG) the results were 2.15 and 1.89 $m^2$-year, a difference of 12%. As the production of the feeds represents practically the totality of the impacts observed for this category, we can conclude that the biggest difference found in the LCA, referring to animal production, is due to the better performance observed for the animals that received feed with less protein content.

The assessment of the environmental impact in the swine production chain is complex, since elements that can cause environmental problems are emitted in different stages of the production chain, such as fertilizer production, food cultivation, transport, feed production, animal production, manure management, among others. Changes that seek to reduce the emission of some pollutant must be evaluated in a systemic way, since this can be beneficial for one stage of production and result in losses in the others. Every change, before being implemented, must be discussed and evaluated so that the desire of a part of the population does not result in a problem for the entire pig production chain.

## 5. Conclusion

The reduction of crude protein and supplementation of industrial amino acids in diets for growing pigs (30 - 50 kg) promoted improvement in the DWG and final weight of the animals, combined with less excretion of N and P. Through LCA and performance and metabolism data, it was concluded that for the acidification, eutrophication and land occupation categories, impacts were mitigated as the protein concentration was reduced.

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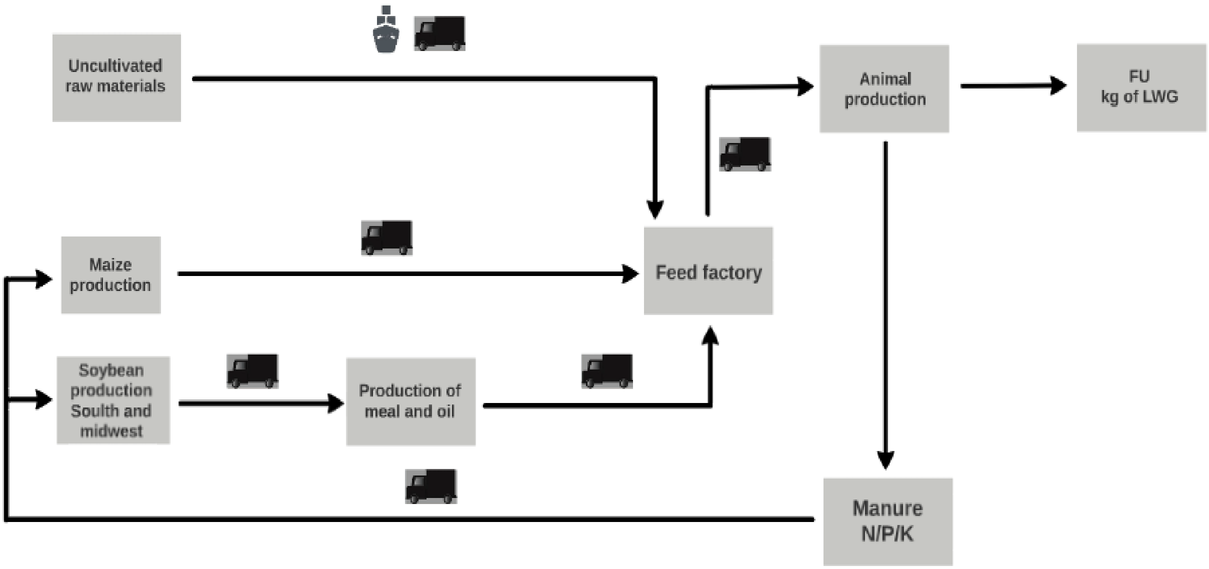


**Figure 1.** System boundaries of growing pigs production.

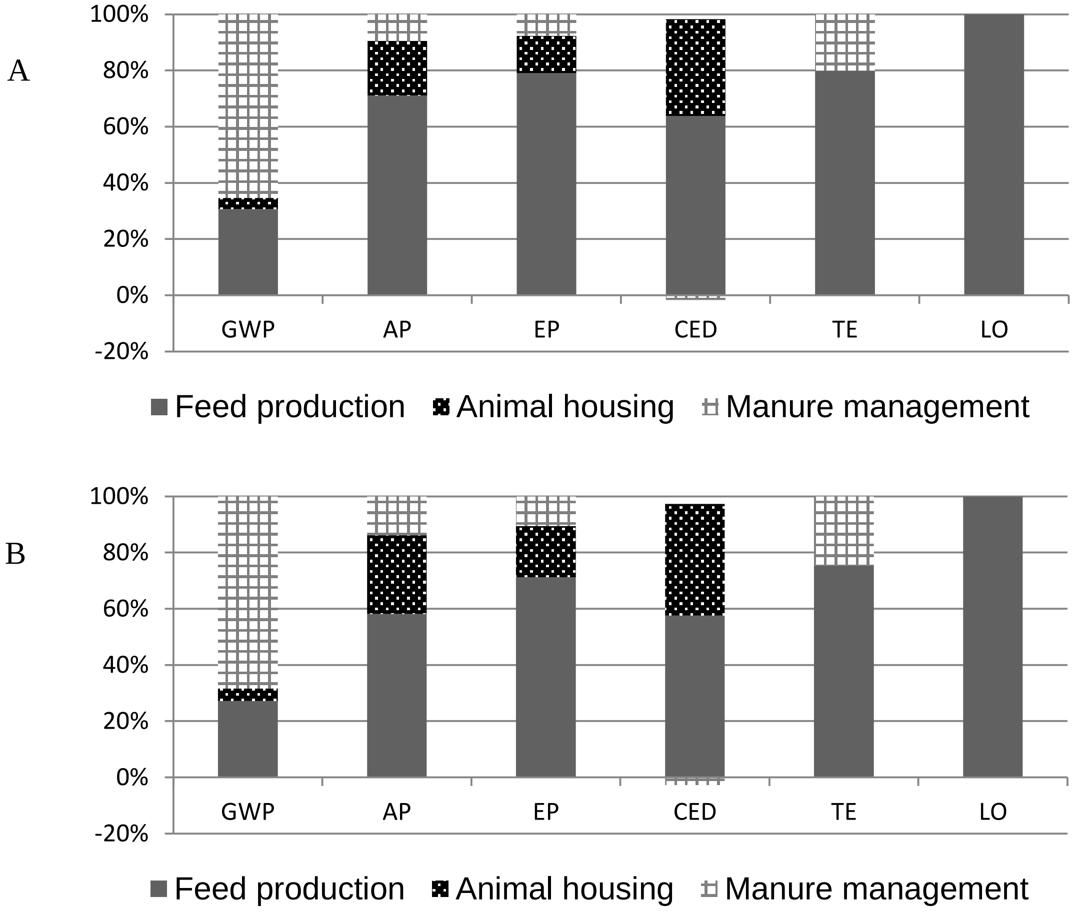


**Figure 2.** Relative contribution of the low protein and high protein system to the categories global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO).

**Table 1.**Ingredients, chemical composition of diets with reduction on crude protein level

| Ingredients(%) | Crude protein content (%) | | | |
|---|---|---|---|---|
| | 18,15 | 17,15 | 16,15 | 15,15 |
| Maize | 66,18 | 69,10 | 72,05 | 75,06 |
| Soybean meal | 27,48 | 24,39 | 21,24 | 18,01 |
| Soybean oil | 2,727 | 2,604 | 2,472 | 2,310 |
| Dicalcium phosphate | 1,433 | 1,455 | 1,478 | 1,501 |
| Limestone | 0,701 | 0,713 | 0,725 | 0,737 |
| Sodium bicarbonate | - | 0,155 | 0,314 | 0,475 |
| Salt | 0,460 | 0,343 | 0,236 | 0,127 |
| Premix[1] | 0,400 | 0,400 | 0,400 | 0,400 |
| L-Lysine HCl 78,0% | 0,305 | 0,400 | 0,497 | 0,597 |
| DL-Methionine 99,0% | 0,115 | 0,142 | 0,170 | 0,199 |
| L-Threonine 98.5% | 0,128 | 0,170 | 0,213 | 0,258 |
| L-Tryptophan 98,0% | 0,033 | 0,049 | 0,065 | 0,082 |
| L-Valine 98,0% | - | 0,034 | 0,088 | 0,143 |
| L-Isoleucine 100,0% | - | - | 0,011 | 0,066 |
| Antioxidant[2] | 0,015 | 0,015 | 0,015 | 0,015 |
| Growth promoter[3] | 0,020 | 0,020 | 0,020 | 0,020 |
| Calculated composition % | | | | |
| Calcium | 0,722 | 0,722 | 0,722 | 0,722 |
| Available phosphorus | 0,357 | 0,357 | 0,357 | 0,357 |
| Sodium | 0,195 | 0,190 | 0,190 | 0,190 |
| Potassium | 0,715 | 0,668 | 0,619 | 0,570 |
| Chlorine | 0,407 | 0,356 | 0,313 | 0,268 |
| SID lysine | 1,069 | 1,069 | 1,069 | 1,069 |
| SID methionine | 0,357 | 0,370 | 0,385 | 0,399 |
| SID met+cys | 0,631 | 0,631 | 0,631 | 0,631 |
| SID threonine | 0,695 | 0,695 | 0,695 | 0,695 |
| SID tryptophan | 0,214 | 0,214 | 0,214 | 0,214 |
| SID valine | 0,755 | 0,738 | 0,738 | 0,738 |
| SID isoleucine | 0,680 | 0,629 | 0,588 | 0,588 |
| SID histidine | 0,435 | 0,408 | 0,380 | 0,351 |
| SID phenylalanine | 0,796 | 0,741 | 0,686 | 0,629 |
| Metabolizable energy (kcal $kg^{-1}$) | 3350 | 3350 | 3350 | 3350 |
| Net energy (kcal $kg^{-1}$) | 2540 | 2554 | 2569 | 2584 |
| E. Balance. (mEq $kg^{-1}$) | 152,81 | 152,81 | 152,83 | 152,75 |
| Ratio AAE:AANE | 46:54 | 46:54 | 47:53 | 48:52 |

[1]Premix should provide at least the following nutriente amounts per kg of feed:: vitamin A – 4000 UI; vitamin D3 – 600 UI; vitamin E – 12 UI; vitamin K3 – 3 mg; vitamin B1 – 0.6 mg; vitamin B2 - 3.5 mg; vitamin B6 – 1; vitamin B12 – 18 mg; niacin – 20 mg; pantothenic acid – 10 mg; folic acid – 1 mg; biotin - 0.03 mg; choline chloride – 0,16 g; iron – 35 mg; copper – 15 mg; manganese – 25 mg; zinc – 0.075 g; iodine – 1 mg; selenium 0.3 mg, [2]BHT; [3]leucomycin.

**Table 2.** Life cycle assessment, per kg of feed, in pig diets (30-50 kg), containing decreasing levels of crude protein (CP) and supplementation of synthetic amino acids

| | Crude protein (%) | | | |
|---|---|---|---|---|
| | 18,15 | 17,15 | 16,15 | 15,15 |
| GWP, g $CO_2$-eq. | 410 | 424 | 440 | 461 |
| AP, g $SO_2$-eq. | 10,61 | 11,07 | 11,55 | 12,05 |
| EP, g $PO_4$-eq | 4,38 | 4,39 | 4,40 | 4,42 |
| CED, MJ-eq. | 5,37 | 5,66 | 6,02 | 6,50 |
| ET, g 1,4-DCB-eq. | 4,63 | 4,75 | 4,89 | 5,07 |
| LO, $m^2$-year | 1,11 | 1,08 | 1,06 | 1,03 |

Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO)

**Table 3.** Nitrogen and phosphorus balance of growing pigs fed diets with crude protein reduction and amino acids supplementation

| | Crude protein (%) | | | | Standard error | P-value | |
|---|---|---|---|---|---|---|---|
| | 18,15 | 17,15 | 16,15 | 15,15 | | Lin. | Quad. |
| N Intake (g $d^{-1}$) | 42,69 | 40,12 | 38,01 | 35,60 | 0,889 | <0,001[1] | 0,895 |
| N Feces (g $d^{-1}$) | 5,23 | 4,58 | 4,89 | 4,30 | 0,167 | 0,111 | 0,926 |
| N Urine (g $d^{-1}$) | 11,27 | 9,49 | 8,53 | 6,47 | 0,514 | <0,001[2] | 0,655 |
| N Excreted (g $d^{-1}$) | 16,50 | 14,07 | 13,42 | 10,76 | 0,628 | <0,001[3] | 0,819 |
| N Retention (%) | 61,48 | 65,02 | 64,74 | 69,93 | 0,923 | 0,003[4] | 0,479 |
| P Intake (g $d^{-1}$) | 7,96 | 7,56 | 7,41 | 7,38 | 0,139 | 0,004[5] | 0,146 |
| P Feces(g $d^{-1}$) | 4,04 | 3,52 | 3,52 | 3,24 | 0,111 | 0,002[6] | 0,146 |
| P absorbed (%) | 49,39 | 53,50 | 52,50 | 56,05 | 0,904 | 0,017[7] | 0,857 |

Linear effect[1] y= -0,425369 + 2,33066x ($R^2$=1,00), Linear effect[2] y= -16,9499 + 1,52642x ($R^2$=0,98), Linear effect[3] y= -16,1960 + 1,76183x ($R^2$=0,96), Linear effect[4] y=106,973 – 2,45713x ($R^2$=0,86), Linear effect[5] y=4,41227 + 0,186837x ($R^2$=0,83), Linear effect[6]= -0,365033+0,232662x ($R^2$=0,86), Linear effect[7]= 83,8951 – 1,8295x ($R^2$=0,79).

**Table 4.** Final weight, daily weight gain (DWG), feed conversion rate (FCR), daily feed intake (DFI), backfat thickness (BT), depth of *longissimus lumborum* (LL) muscle and plasma urea of growing pigs fed diets with crude protein reduction and amino acid supplementation

| | Crude protein (%) | | | | Standard error | P-value | |
|---|---|---|---|---|---|---|---|
| | 18,15 | 17,15 | 16,15 | 15,15 | | Lin. | Quad. |
| Final weight, kg | 49,84 | 50,25 | 52,65 | 52,12 | 0,426 | 0,020[1] | 0,578 |
| DWG, kg | 1,034 | 1,045 | 1,184 | 1,150 | 0,029 | 0,011[2] | 0,594 |
| FCR, kg | 1,933 | 1,879 | 1,851 | 1,840 | 0,022 | 0,133 | 0,634 |
| DFI, kg | 1,991 | 1,967 | 2,185 | 2,105 | 0,039 | 0,128 | 0,717 |
| BT, cm | 0,56 | 0,59 | 0,67 | 0,67 | 0,028 | 0,062 | 0,718 |
| LL, cm | 3,80 | 3,82 | 3,68 | 4,00 | 0,079 | 0,459 | 0,294 |
| Urea mg $dL^{-1}$ | 28,38 | 22,75 | 18,40 | 22,58 | 1,557 | 0,085 | 0,083 |

Linear effect[1] y= 67,2979 – 0,948293x ($R^2$=0,75), Linear effect[2] y= 1,96421 – 0,0507608x ($R^2$=0,71)

**Table 5.** Potential environmental impacts, per kg of body weight gain, pf growing pigs from 30 to 50 kg, with crude protein reduction and amino acid supplementation

| | Crude protein (%) | | | | *P*-value | |
|---|---|---|---|---|---|---|
| | 18,15 | 17,15 | 16,15 | 15,15 | | Lin |
| GWP, kg $CO_2$-eq. | 2,95±0,19 | 2,87±0,30 | 2,82±0,11 | 2,80±0,26 | 0,398 | |
| AP, g $SO_2$-eq. | 35,34±2,33 | 34,25±3,60 | 33,18±1,49 | 31,58±2,80 | 0,015 | 0,002 |
| EP, g $PO_4$-eq | 11,90±0,77 | 11,36±1,19 | 10,87±0,46 | 10,31±0,92 | 0,001 | <0,001 |
| CED, MJ-eq. | 17,35±1,20 | 17,44±1,45 | 17,22±0,99 | 18,36±1,81 | 0,224 | |
| TE, g 1,4-DCBeq. | 11,89±0,79 | 11,09±1,21 | 11,58±0,49 | 11,69±1,12 | 0,253 | |
| LO, $m^2$-year | 2,15±0,14 | 2,03±0,21 | 1,96±0,08 | 1,89±0,18 | 0,005 | <0,001 |

Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO)

## IV- Lower protein intake for growing pigs (50-70 kg) reduces nitrogen excretion, but promotes different environmental impacts when using life cycle assessment

**Abstract:** The objective of this work was to evaluate the performance, digestibility and environmental impact of pigs in the growth phase (50-70 kg) receiving diets with reduction of crude protein and supplementation of industrial amino acids. In the metabolism experiment, 20 crossbred barrows with an initial average weight of 63.62 ± 2.21 kg were used, housed in metabolic cages and distributed in a randomized block design, with four treatments and five replications, one animal per experimental unit. In the performance experiment, 40 crossbred barrows were used, with an initial average weight of 49.92 ± 0.92 kg, distributed in a randomized block design, with four treatments, ten replications and one animal per experimental unit. The treatments used in the two experiments consisted of four diets containing 16; 15; 14 and 13% CP, and supplementation of industrial amino acids so that the requirements of all digestible amino acids are met. For performance, backfat thickness and depth of the *longissimus lumborum* muscle, no differences were observed (P> 0.05) between the treatments evaluated. Plasma urea was lower (P <0.05) for animals fed diets with protein reduction, as well as the excretion of N urine and total N, but no differences (P> 0.05) were observed for retained N, P absorbed, P ingested and P feces. Through the life cycle assessment it was possible to conclude that for the categories of eutrophication potential (P = 0.051) and land occupation (P = 0.063), the protein reduction mitigated the environmental impacts when the data referring to soybean meal was used produced in the southern region, but the protein reduction provided an increase in impact when the category evaluated was that of cumulative energy demand, both for analysis performed considering the soybean produced in the south (P = 0.003) and that produced in the central west region (P = 0.044).

Keyword: amino acids, cumulative energy demand, eutrophication.

### 1. Introduction

The increase in the world population, combined with the urbanization process and better family income will promote greater demand for food of animal origin. Meeting this demand will be a challenge to the productive sector and may pose a threat to the environment (Sajeev et al., 2018), if production is poorly conducted. Many studies have highlighted the negative effects of the animal production sector, which are often correlated with gas emissions, such as ammonia ($NH_3$), a substance responsible for eutrophication of lakes and rivers and soil acidification (Sajeev et al., 2018). $NH_3$ is formed from nitrogen (N) present in the animals' feces and urine. In addition to N, another element found in manure is phosphorus (P), which is also capable of promoting environmental eutrophication.

The concern with the environmental impacts caused by the excess of N is worldwide, as a survey carried out in China showed that the disposal of N carried out in water sources is approximately 14.5 megatons per year, a value 2.7 times higher than the estimated as “safe” (approximately 5.2 megatons per year). Crops and animal production are responsible for 35% and 24%, respectively, of these impacts (Yu et al., 2019). Improvements in production processes (diet, animal management, manure management, use of nutrients) are pointed out as ways to mitigate these impacts.

The reduction of dietary crude protein (CP) in pig production is seen as a way to reduce the excretion of N without harming the animals' performance (Monteiro et al., 2019). The moderate reduction of dietary protein for pigs can reduce not only the excretion of N, but also the emission of $NH_3$, however the sharp reduction can promote a decrease in the performance of the animals (Wang et al., 2020). In order to avoid a drop in performance, the daily amino acid requirement of the animals must be met with industrial amino acid supplementation (AAI), thus there will be no excess of amino acids and will promote better use of N.

Currently, there is a tendency to reduce protein content, this can be confirmed through the tables of nutritional requirements for pigs (Rostagno et al., 2011; Rostagno et al., 2017). In addition to the lower excretion of N, protein reduction can alter intestinal flora, produced metabolites, gene expression, performance and pig carcass composition (He et al., 2016; Monteiro et al., 2016; Fan et al., 2017; Zhao et al., 2019; Wang et al., 2020).

However, the lower excretion of N is not a guarantee of less environmental impact either in the production of pigs, as changes in nutritional composition can cause different impacts along the production chain. The swine production chain involves several stages, including the production of grains, fertilizers and additives, as well as transportation, drying, storage and handling and application of manure, among others.

As the emission of substances occurs throughout the chain, it must be assessed in an integrated manner, and an effective tool for this type of assessment is the life cycle assessment (LCA) (Dourmad et al., 2014).

Although there are studies evaluating protein reduction, there are still questions about whether it can impair the performance of animals, since, even with AAI supplementation, the reduction may promote changes in the composition of the intestinal flora and metabolism of nutrients. In addition, the reduction has the main benefit of lower environmental impact, which is provided by the lower excretion of N, however this assessment must be carried out holistically. Thus, the objective of this work was to evaluate the environmental impact, through LCA, of diets with reduction of crude protein and supplementation of AAI for crossbred barrows in the growth phase (50-70 kg).

## 2. Material and methods

### 2.1 Goal and scope

This study was carried out at the State University of Maringá (UEM) which is located in the northwest region of Paraná, a state of great representativeness in pig production in Brazil. It aimed to evaluate the environmental impact of diets with reduction of crude protein and supplementation of industrial amino acids for crossbred barrows in the growth phase (50-70 kg) and to generate information that can be used by the pig industry, researchers and society in the search for the sustainability of the productive system.

### 2.2 Description of the system

Two experiments were carried out to perform the LCA. Experiment I: digestibility of four diets with protein reduction, to evaluate the digestibility of nutrients and to count the excretion of manure (feces and urine). Experiment II: performance, plasma urea, backfat thickness (BT) and the depth of the *longissimus lumborum* (LL) muscle of animals that received the same diets used in experiment I. The complete description of the experiments is performed in items 2.10 and 2.11.

### 2.3 System and functional unit limits

In order to perform the LCA, the stages of animal production, cultivation, drying and processing of grains, transportation of ingredients to the factory and from the factory to the farm, production of feed, storage, transport and application of manure to the soil were considered. The impacts were considered in a specific phase (50–70 kg), so the impacts related to the process of transport and slaughter of the animals were not evaluated. According to Reckmann et al. (2013), the slaughter process has a low environmental impact when compared to the stages of feed production and animal production, representing only 1 and 8% of the total impacts for categories such as acidification and eutrophication potential, respectively.

Although the use of the area necessary for the construction of the facilities was not used in the analysis, the area necessary for the production of grains was measured in the system. The manure generated during the animals' housing phase was accounted for and used as a source of N, P and K in the fertilization of crops, reducing the use of chemical fertilizers. The equivalence factor (EF) used for N was 75%, assuming an extra loss of 5% in the form of nitrate (Garcia-Launay et al., 2014; Nguyen et al., 2010). For the P and K present in the manure, the EF used was 100% (Sommer et al., 2008). All impacts related to manure management, including storage and application, were allocated and accounted for. The functional unit was one kg of live weight gain (LWG) in the 50-70 kg growth phase. The definition of the system limits is shown in figure 1, and is based on Nguyen et al. (2010).

### 2.4 Life cycle inventory analysis

The resources used and the emissions associated with the production and transport of raw materials for grain production were obtained through the Ecoinvent version 3 database (SimaPro LCA software 8.0, Pré Consultants). The use of electrical energy for lighting and ventilation of the warehouses was considered, however, the emissions and resources used for the construction of the facilities, vaccines, veterinary drugs, detergents and disinfectants used to clean the facilities were not evaluated (Arrieta and González, 2019).

### 2.5 Grain Production

As they are the most important regions in soy production in Brazil, it was assumed that the soy used was produced in the south and mid-west (CONAB, 2018).

The inventory for soy cultivation was based on Silva et al. (2010), with an economic allocation being made to determine the impacts related to oil and soybean meal (Garcia-Launay et al., 2014). The allocation is the partition of environmental impacts between different co-products, and can be carried out based on physical characteristics (mass and energy) or other factors, such as economic (Arrieta and González, 2019). The inventory for maize cultivation was based on Avarenga et al. (2012).

### 2.6 Uncultivated raw materials

The inventories for salt, dicalcium phosphate, sodium bicarbonate, limestone and premix were obtained from Wilfart et al. (2016). For the production of antioxidant, the same demand for resources and energy necessary for the production of premix was considered. For the production of the amino acids L-lysine HCl, DL-methionine and L-threonine, the inventory was obtained through Mosnier et al. (2011) that consider chemical and biological processes in the synthesis of these products. For the production of L-tryptophan, L-valine and L-isoleucine, the demand for resources and energy was twice as high as for the production of L-lysine (Garcia-Launay et al., 2014).

### 2.7 Transport specifications

For the transportation of food and feed, the methodology proposed by Silva et al. (2010). For the transportation of imported products, transportation was initially established by sea and later by road. Given the importance of the southern region of Brazil in pig production, responsible for approximately 69% of the total number of animals slaughtered in the country (ABPA, 2018), grain production in the main producing centers of this region was considered, as well as the region where the farm was located.

### 2.8 Feed formulation and production

The treatments consisted of four diets with decreasing levels of CP. The levels used were 16; 15; 14 and 13% CP (Table 1), with the requirements for digestible amino acids proposed by Rostagno et al. (2017) were met with the use of the amino acids L-lysine, DL-methionine, L-threonine, L-tryptophan, L-valine and L-isoleucine. The amino acid composition of corn and soybean meal was determined at Evonik Industries. For the calculation of digestible amino acids contained in foods and industrial amino acids, the standardized ileal digestibility coefficients proposed by Rostagno et al. (2017). Sodium bicarbonate was used to adjust the electrolyte balance of the diets.

The amino acids lysine, methionine, threonine, tryptophan, valine, isoleucine, arginine, leucine, phenylalanine and histidine were considered essential amino acids in the calculation of the relationship between essential amino acids (AAE): non-essential amino acids (AANE). For this calculation, the total concentration of each of these amino acids was considered, as well as the amount of N present in its composition. The N values used were those proposed by Rostagno et al. (2017). The N for the AANE was obtained through the difference between the total N of the diets and the N present in the AAE, adapted from Toledo et al. (2014).

The data related to the production process of the feeds were based on those proposed by Garcia-Launay et al. (2014).

### 2.9 Animal production

The procedures performed in experiments I and II were approved by the Animal Use Ethics Committee of the State University of Maringá (CEUA n ° 2846260819).

### 2.10 Experiment I

Twenty crossbred barrows, with an initial average weight of 63.62 ± 2.21 kg were used, housed in metabolic cages, distributed in a randomized block design, with four treatments and five repetitions, one animal per experimental unit.

The amount of feed provided daily was calculated based on the metabolic weight ($kg^{0.75}$) and the average consumption recorded during the adaptation period. To avoid losses and facilitate ingestion, the rations were moistened with water, in approximately 30% of the ration, and supplied twice daily (7:30 am and 3:30 pm). After each meal, the water was provided in the feeder in the proportion of 3 mL of water / g of feed, to avoid excessive water consumption.

To determine the period of beginning and end of the collection of feces, 2% ferric oxide ($Fe_2O_3$) was added to the diets. Feces were collected daily and packed in plastic bags and stored in a freezer (-18 ° C), to be later analyzed. The urine was filtered and collected daily in plastic buckets containing 20 mL of HCl 1: 1, to avoid nitrogen volatilization and bacterial proliferation. Aliquots of 20% of the total volume were removed and packed in plastic bottles and frozen (-18 ° C).

### 2.11 Experiment 2

#### 2.11.1 Performance

Forty crossbred barrows, with an initial average weight of 49.92 ± 0.92 kg were used, distributed in a randomized block design, with four treatments and ten repetitions, one animal per experimental unit. The animals were weighed at the beginning and at the end of the experimental period to determine daily weight gain (DWG). The rations provided were weighed to determine the daily feed intake (DFI) and feed conversion (FC).

#### 2.11.2 *Longissimus lumborum* and backfat thickness

When the animals reached an average weight of 70.50 ± 3.19 kg, the backfat thickness (BT) and the depth of the *longissimus lumborum* (LL) muscle were evaluated, using equipment consisting of an ecocamera (Aloka® SSD- 500 Vet) coupled to a 14.5 cm and 3.5 MHz probe. For this measurement to be performed, the animals were previously shaved between the tenth and eleventh ribs (Dutra Jr et al., 2001).

#### 2.11.3 Plasma urea

At the end of the experiment, the animals were subjected to a 6-hour fast to collect blood. The samples were collected and transferred to a tube containing EDTA, and subsequently centrifuged at 3000 rpm for 15 minutes. The plasma was transferred to polyethylene microtubes and stored in a freezer. The urea analysis was performed by the colorimetric method, using a commercial kit, following the standard operating procedures described therein.

### 2.12 Laboratory analysis

The rations were analyzed according to the Association of Official Analytical Chemists - AOAC (2005), in terms of dry matter (method 950.46), ash (method 942.05), crude fiber (method 962.09) and nitrogen (method 984.13). The values of phosphorus, copper, zinc and potassium were obtained using a UV-Vis spectrophotometer. The nitrogen content in the urine was also evaluated. In the feces, the levels of nitrogen, phosphorus, dry matter, ash and crude fiber were determined, following the same methodology used in the analysis of the rations.

### 2.13 Life cycle impact assessment

#### 2.13.1 Emissions from pig production

Emissions were calculated for the stages of animal housing, storage and application of manure, as proposed by Monteiro et al. (2016). Through laboratory analysis, the amounts of N, P and excreted organic matter were obtained, for later determination of the amounts of each nutrient available for application.

The excretion of the minerals copper (Cu), zinc (Zn) and potassium (K) were obtained through the equations proposed by Rigolot et al. (2010a). The $NH_3$ emissions resulting from the stages of accommodation and manure management were carried out considering the temperature of the shed, and were calculated according to the equations proposed by Rigolot et al. (2010b) and the IPCC (2006).

#### 2.13.2 Characterization factors

The LCA was based on the CML 2001 (baseline) version 3.02 method, implemented in Simapro version 8.05 (PRé Consultants), adding the following categories: land occupation from CML 2001 (all categories) version 2.04 and cumulative energy demand version 1.8 (non-renewable fossil + nuclear).

The characterization factors used to calculate the impact of growing pig production were: global warming potential (GWP, kg $CO_2$-eq.), acidification potential (AP, g $SO_2$-eq.), eutrophication potential (EP, g$PO_4$- eq), terrestrial ecotoxicity (TE, g 1,4-DCB-eq.), cumulative energy demand (CED, MJ-eq.) and land occupation (LO, $m^2$-year), for the GWP category it was considered the global warming potential over a 100-year horizon.

### 2.14 Interpretation and statistical analysis

The retention coefficients of N and P were obtained for each of the experimental diets. These coefficients were used to determine the amounts excreted of each element during the growth period, using the data obtained through the performance evaluation of the animals. The LCA calculations were evaluated for each animal, and according to the consumption and excretion data of the animals, the environmental profile of each system was constructed, with the aid of the SAS software (SAS Inst. Inc., Cary, NC).

The performance, excretion and environmental impact data were subjected to analysis of variance using the SAS GLM procedure. The statistical model included the treatment and block effect. The significant data were submitted to regression analysis. The degrees of freedom related to the CP levels were divided into polynomials. All analyzes were performed using SAS software version 9.2.

## 3. Results

### 3.1. Life cycle assessment of feed

The formulated diets assess the environmental impacts considering soy produced in different regions of Brazil, the southern and midwestern regions. The impact categories that present the greatest divergence between the results observed for these two regions were GWP and CED.

The reduction of CP, in diets formulated considering soybean meal from the southern region, increased the impacts for the categories GWP, AP, EP, CED and TE (Table 2). The only exception was observed for LO, in which the lowest protein concentration resulted in mitigation of the impact for this category.

For diets formulated considering soybean meal from the midwest region, the protein reduction also resulted in an increased environmental impact for CED, however for GWP it was observed an inverse behavior, since the reduction of CP provided a reduction in GWP. Regardless of the protein level evaluated, diets formulated considering soybean meal produced in the midwest region, resulted in greater impact when compared to diets produced considering the meal obtained in the southern region.

### 3.2. Metabolism and performance

The higher concentration of N in the diet promoted a linear increase in the ingested N ($P = 0.002$), excretion of N in the urine ($P = 0.006$) and also in the total N excreted ($P < 0.001$). However, no significant differences were observed for N in feces, N retained, P ingested, P in feces and P absorbed (Table 3).

In the performance evaluation, there was no significant difference for the evaluated variables (DWG, FCR and DFI), as well as for the carcass characteristics (BT and LL). However, the lowest protein concentration promoted a linear reduction ($P < 0.001$) in the plasma concentrations of urea in growing pigs (Table 4).

### 3.3. Life cycle assessment of growing pig production

As mentioned previously, the impact categories evaluated were GWP, AP, EP, CED, TE and LO, but the categories of GWP and CED were evaluated under two productive contexts, with soybean meal coming from soy produced in the south or midwest. GWP and CED were the categories that showed the greatest divergences between the observed results, so they were presented in this way.

The results related to animal production, calculated using data obtained from diets that used soybean meal from the southern region, ranged from 3.06 to 2.93 kg $CO_2$-eq, 41.41 to 37.91 g $SO_2$-eq and 13.31 to 12.29 g 1,4-DCB eq, per kg of LWG for categories GWP, AP and TE, respectively. However, no statistical differences were observed between the treatments evaluated ($P > 0.05$), for these impact categories (Table 5).

However, EP ($P = 0.036$) and LO ($P = 0.019$) showed a linear reduction in impacts when the diet changed from 16 to 13% of CP when considering soy from the southern region. For the CED category there was the opposite effect, since the reduction of dietary CP promoted a linear increase in environmental impact.

Linear increase in the environmental impact on animal production was also observed for CED when the diet went from 16 to 13% of CP when considering soybean meal from the Midwest region, however, no significant difference was observed for GWP. The results obtained for GWP and CED, per kg of LWG, are higher when considering the production of feeds the soybean meal from grown in the central-west region when compared to that obtained for GWP and CED per kg of LWG of the animals produced considering the bran from the southern region.

## 4. Discussion

### 4.1. Feed

For diets that were formulated considering soybean from the southern region, the protein reduction promoted a 13% increase in the kg of feed produced for the GWP category (Table 2). Industrial amino acids are among the foods used in formulating diets with the greatest environmental impact for this category (Mosnier et al., 2011). Thus, it is expected that protein reduction promotes an increase in the inclusion of amino acids in diets and, consequently, the environmental impact for this category is higher in diets with lower protein concentration, since the requirement for essential amino acids must be met to ensure optimal performance of pigs.

The same behavior observed for GWP was also observed in relation to CED and according to Mosnier et al. (2011), the production of one kg of amino acids, such as L-lysine-HCl and L-threonine, involves an energy expenditure 92% higher when compared to the production of the same amount of soybean meal. Thus, the reduction in protein from 16 to 13% promoted an increase in CED from 23 and 11% for diets that used soy from the south and mid-west, respectively.

### 4.2. Metabolism and performance

The reduction in CP provided lower consumption of N by the animals, which reduced from 46.78 g $d^{-1}$ to 39.22 g $d^{-1}$ for animals that received diets of 16 and 13% CP, respectively. The consumption of N influenced the total excretion of N, which was 23% higher for animals that received a 16% CP diet when compared to animals that received a 13% CP diet. These results are in agreement with those obtained by Toledo et al. (2014), who concluded that the reduction in CP of the pig diet was responsible for decreasing and excreting N, mainly through urine.

Although the consumption and excretion of N were directly related to the concentration of N present in the diets, this behavior was not observed for N retention, with values ranging between 65.28 and 58.18%. As in this study, Monteiro et al. (2017) also observed that the reduction in CP provided a significant reduction in the consumption and excretion of N, without significant differences being observed in relation to the retained N.

The absorbed P ranged from 51.06 to 42.88%, which is close to those obtained by Monteiro et al. (2019), which were 49.2 to 41.0%. The lower inclusion of soybean meal in diets with CP reduction may provide a reduction in the concentration of phytic phosphorus in the feed, improving the absorption of phosphorus by animals. The diet with the lowest protein concentration shows a 9% reduction in the concentration of phytic phosphorus, when compared to the one with the highest protein, but no significant differences were observed in phosphorus absorption due to the CP levels of the diets.

The protein reduction decreased the excretion of N to the environment without the animals' performance being impaired, this proves that the supplementation of industrial amino acids met the daily requirement of the animals. The DWG ranged from 1.166 to 1.052 kg, even the treatment with the lowest protein consumption provided nutrients for the animals to reach the expected DWG for this phase (1.047) (Rostagno et al., 2017).

FCR and DFI were also not influenced by the protein reduction in the diet. These results are different from those obtained in other studies, in which the protein reduction worsened the DWG, DFI and FCR (Li et al., 2018; He et al., 2016). The difference between the results found in our study and the authors mentioned above can be explained by the marked protein reduction proposed by the authors, and also by amino acid supplementation, since they chose not to supplement the diets with valine and isoleucine. This results in a deficiency of these amino acids in diets with a lower protein concentration. In the work developed by He et al. (2016), the consumption of valine in the growth phase was 7.72 g $d^{-1}$ and 13.25 g $d^{-1}$ for animals that received diets with 12.35 and 18.27% CP, respectively. This huge difference in amino acid consumption may have limited animal performance.

In the present study, the digestible valine consumption was approximately 16.23 g $d^{-1}$, referring to animals that received diets containing 16% CP; and 14.71 g $d^{-1}$ for animals that received diets with 13% CP. The digestible valine requirement for this phase (50-70 kg) is 14.98 g $d^{-1}$ (Rostagno et al., 2017).

Although the animals in the treatment with the lowest protein concentration consumed 98.18% of the digestible valine requirement proposed by Rostagno et al. (2017), this deficiency did not compromise the animals' performance. Other studies have already observed that the daily requirement for amino acids may be slightly overestimated in the tables proposed by Rostagno et al. (2011) (Pasquetti et al., 2015;

Monteiro et al., 2017), however this higher demand for amino acids may be a guarantee margin that aims to meet the requirement of the national herd (Monteiro et al., 2017).

The results obtained for plasma urea and excretion of N in the urine corroborate what was observed in the performance evaluation, as the animals that consumed diets with a higher protein concentration, consequently, consumed an amount of amino acids above the daily requirement. As demonstrated for digestible valine, the other amino acids (isoleucine, histidine, phenylalanine, among others) were also consumed in greater amounts in diets with a higher protein concentration. This resulted in the greater deamination of these amino acids and in the linear increase of plasma urea and N in the urine, because in addition to the greater amount of some amino acids in the diet of higher protein concentration, there is also a greater imbalance of essential amino acids providing greater deamination of these.

The relationship between the AAE: AANE of the diets ranged from 45:55 to 47:53 for the diets with the highest and lowest protein concentration, respectively. Diets with reduced crude protein and high inclusion of industrial amino acids can promote an increase in this relationship and limit the synthesis of AANE, according to Wang and Fuller et al. (1989) the ideal ratio between AAE: AANE is approximately 45:55. The data referring to the performance of the animals allow us to conclude that although there was a variation in the AAE: AANE ratios between diets, this variation did not limit the synthesis of AANE, since there was no difference in the performance of the animals.

### 4.3. LCA of animal production

The values found in relation to GWP ranged from 2.93 to 3.06 kg $CO_2$-eq. per kg of LWG and from 3.67 to 3.38 kg $CO_2$-eq. per kg of LWG for animals fed diets that used soybean meal from the southern and central-western regions, respectively. There was no difference between the treatments evaluated, but the impact was less for the animals that received the diet that used soybean meal from the southern region.

The difference in relation to the environmental impact of the production of the diets was what determined the highest result for the kg of LWG of the animals that received diets with soybean meal from the central-west region. The soybean grown in the central-west region has the aggravating factor of being a food produced in an area of recent deforestation, this implies the accounting for $CO_2$-eq. emitted during the cultivation of this plus $CO_2$-eq. referring to land use change (Silva et al., 2010; Reckmann et al., 2016).

In the central-west region, transportation is another aggravating factor when compared to the distances traveled in the south. Although the main differences found in the environmental impact between soybeans grown in the south and midwest are due to deforestation and transportation, another factor that should be highlighted is the greater use of fertilizers in the cultivation of soybeans produced in the midwest region (Silva et al., 2010; Silva et al., 2014).

The manure management stage was the one that most contributed to the impacts observed for the GWP category. This stage represents 64.03% (diets with bran from the southern region) and 54.78% of the impacts observed (diets with bran from the central-west region) for this category (Figure 2). The food production stage also had a significant impact for this category, with 31.78 and 41.64% of kg $CO_2$-eq emissions. per kg of LWG for animals fed diets that used soybean meal in the south and midwest regions, respectively.

The results obtained are in agreement with those observed by Bandekar et al. (2019) who concluded that the stages of waste management and food production are the ones that most contributed to the GWP category. The authors also report that management that results in a drop in the performance of the animals may enhance the environmental impacts for this category, as the animal will have to consume a greater amount of food and will excrete a greater amount of manure until reaching the ideal slaughter weight.

The most important element emitted during the manure management stage for the GWP category is $CH_4$, the emission of this element can be intensified or mitigated according to the temperature of the environment (IPCC, 2006). The average temperature recorded in the experimental period was 24.63 ° C, if we use the temperature obtained in an experiment in the previous year, 26.03 ° C, the average value obtained for the four treatments that used soybean meal from the south region, 3.01 kg $CO_2$-eq. per kg of LWG would be 3.25 kg $CO_2$-eq. per kg of LWG.

For the AP category, no significant difference was observed ($P = 0.1096$) between the treatments evaluated, and varied between 41.41 to 37.91 g $SO_2$-eq. per kg of LWG. Studies show that protein reduction can promote a reduction in AP through less excretion of N in manure and, consequently, less $NH_3$ emission (Reckmann et al., 2016; Wang et al., 2020).

$NH_3$ is emitted from the moment the feces and urine mix, since this gas is formed by the hydrolysis of urea present in the urine, this reaction is catalyzed by the enzyme urease which is present in the feces. This enzyme is produced by a bacterium present in the animals' digestive system (Philippe et al., 2011). In this way, $NH_3$ is the main element emitted responsible for the AP process during the stage of housing the animals and handling manure. According to Reckmann et al. (2013), $NH_3$ was responsible for 93% of the impacts obtained for this category, with a large part of this element being emitted during the animals' housing stage.

Although no difference was observed for AP, the reduction in dietary CP was effective in reducing $NH_3$ emission. There was a reduction of 31.23% in the emission of this element during the animal housing and manure management stages, when compared to diets with higher and lower protein concentrations. This value is close to that proposed by Philippe et al. (2011), according to the authors for each 10 g $kg^{-1}$ less in the protein concentration of the diet it is possible to reduce almost 10% in the $NH_3$ emission.

Possibly, the lowest protein concentration was not effective in significantly reducing the environmental impact for AP, as, as can be seen in Table 2 and Figure 2, although the reduction of CP in diets has reduced the impact on the stages of animal housing and manure management, for the feed production stage the effect was opposite. There was an increase in the environmental impact for AP when the kg of feed produced was evaluated, between the diets with the lowest and highest protein value. Another factor that had an influence on the result was the animals' performance, since the impact was calculated on the kg of LWG and there were no significant differences for the DWG, FCR and DFI.

As with AP, the N emitted through $NH_3$ is also responsible for the environmental EP. However, another element that can impact this category is P (Guinée et al., 2002). The results obtained for the EP varied between 13.35 and 12.01 g $PO_4$-eq. per kg of LWG and a linear reduction ($P = 0.036$) was observed in the EP when the diets went from 16 to 13% of CP.

AP and EP showed similar behaviors in relation to the impacts observed during the stages of accommodation and manure management, since the lower protein concentration reduced the $NH_3$ emission, consequently the impact obtained for AP and EP during the stages of accommodation and management of the waste was mitigated. The big difference was observed in relation to the impact related to the production of the diets, since for EP the difference between the impact per kg of feed produced was low, approximately 1%.

Feed production was the stage that most contributed to EP regarding animal production (kg of LWG), representing values between 77.34 and 71.57% of the observed impacts. Similar results were obtained by Monteiro et al. (2016), in which for the EP category the production of diets was the stage that most impacted LCA, and also reported that the use of amino acids was efficient in reducing the impacts for the category. The use of AAI combined with phytase supplementation can bring more significant reductions in the impacts related to EP in the production of pigs and poultry (Kebread et al., 2016).

For the CED category, the protein reduction promoted a linear increase in the impacts obtained, both for those using soybean meal from the southern region ($P < 0.001$), which ranged from 21.33 to 17.88 MJ-eq. per kg of LWG, and for the impacts assessed using the soybean meal from the midwest region ($P = 0.028$), between 22.69 to 20.31 MJ-eq. per kg of LWG.

The reduction of crude protein promotes an increase in the inclusion of AAI, this can be proven through the inclusion of L-lysine, which went from 0.615 to 0.309% in the diets of 13 and 16% of CP, respectively. As the CED is greater for the production of amino acids than for the production of corn and soybean meal (Ogino et al., 2013), its greater inclusion promoted an increase in CED, both for kg of feed produced and for kg of LWG.

In addition to GWP, CED also showed a representative difference when diets were formulated using bran from different regions. The cultivation of soybeans in the central-west region has a greater impact on CED due to the most recent deforestation, transportation and also the use of a greater amount of fertilizers in the cultivation carried out in that region (Silva et al., 2010). According to the author, the distance traveled for the transportation of equipment, seeds, fertilizers, among others, as well as the transportation of the grains to the regional storage facilities, are greater in the midwest region when compared to the south region.

In an assessment of the pork and poultry production chain, Arrieta and Gonzales (2019) highlighted that the production of fertilizers and pesticides contributes approximately 58% of the impacts observed to the CED of the production of the pig diet. Thus, the use of waste to produce energy and biofertilizers is an alternative to mitigate these impacts (Nguyen et al .2010).

The results obtained for TE varied between 13.31 and 12.29 g 1,4-DCB eq. per kg of LWG, however there was no significant difference (P = 0.1647) between treatments. These values are higher than those obtained by Monteiro et al. (2019), but the LCA performed by these authors evaluated the environmental impact of pig production in the nursery phase (15-30 kg) and as the production of diets is the stage that most contributes to the impacts observed for TE, it is expected that a production phase with higher feed consumption and worse feed conversion has a greater impact. As in the aforementioned work, the production of diets was the stage that most contributed to the impacts observed for this category, representing between 77 to 75%.

Protein reduction is achieved through the lower inclusion of soybean meal and the greater inclusion of amino acids in diets. The diet with the highest protein concentration (16% CP) is composed of 21.63% soybean meal, but the diet with the least amount of protein (13% CP) had 12.04% soybean inclusion. As the productivity per hectare of soybean cultivation is lower than that of corn, the lower inclusion of soybean meal in the diet results in reducing the environmental impact for the LO category (Silva et al., 2014).

The lower concentration of protein in the diet reduced the environmental impact for the LO category by 7%. Since we do not consider the area necessary for the construction of the facilities, the impacts observed for this category are due to the production of the feed. Another factor that could alter the results observed would be related to the animals' performance. As there was no significant difference in performance, we can say that the linear reduction (P = 0.019) in the impact for LO, in relation to animal production (kg of LWG), was due to the impacts observed in the production of diets.

## 5. Conclusion

The reduction of dietary CP, associated with supplementation of industrial amino acids for growing pigs, reduced the excretion of N without compromising the animals' performance. The effects related to LCA show that the protein reduction reduced the impacts for the categories eutrophication potential and land occupation, but the impacts for the category cumulative energy demand, both for the diets that used soybean meal from the southern region and those that used soybean meal from the midwest region, were intensified with the reduction of crude protein.

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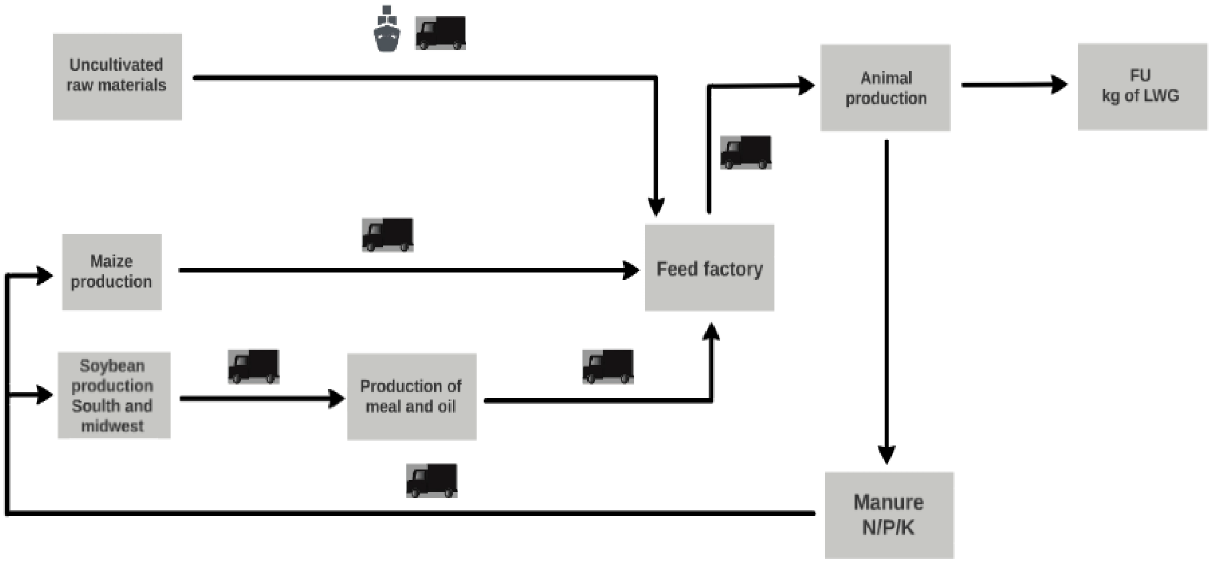


**Figure 1.** System boundaries of growing pigs production.

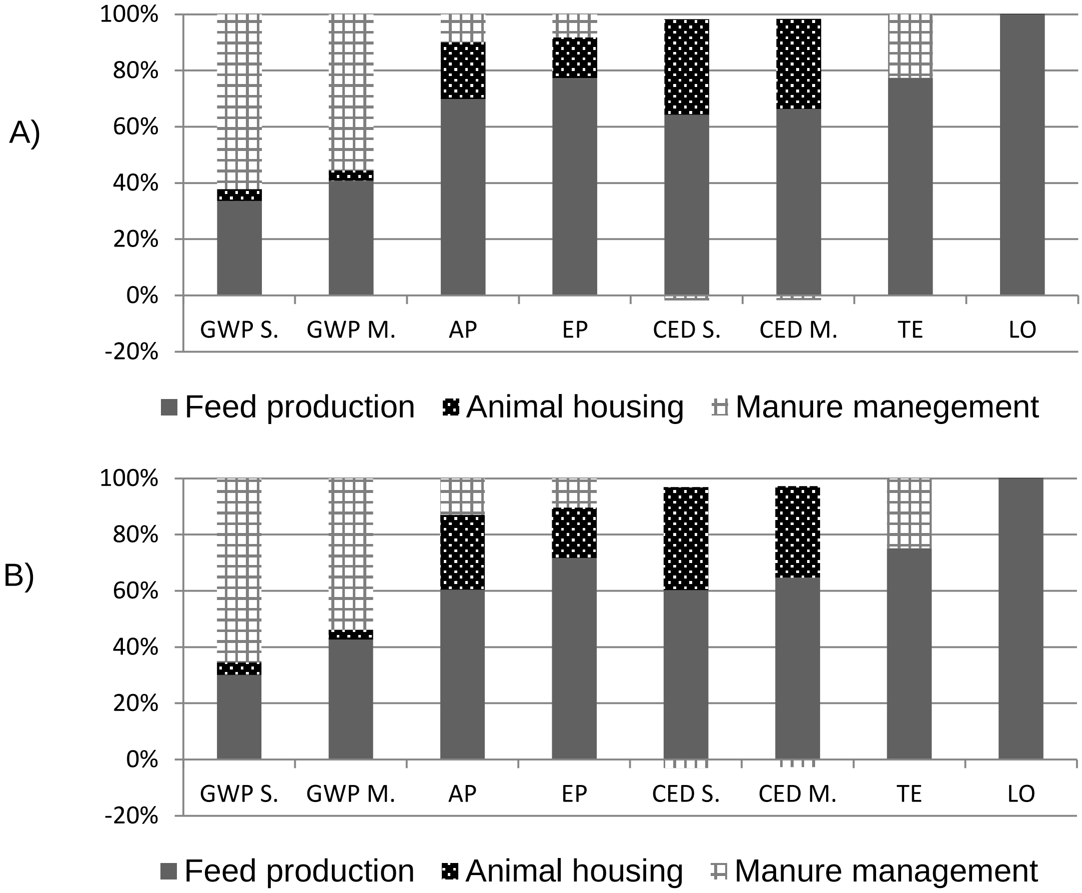


**Figure 2.** Relative contribution of the low protein and high protein system to the categories global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO).

**Table 1.** Ingredients, chemical composition of diets with reduction on crude protein level

| Ingredients(%) | Crude protein content (%) | | | |
|---|---|---|---|---|
| | 16 | 15 | 14 | 13 |
| Maize | 73,075 | 75,980 | 78,965 | 82,034 |
| Soybean meal | 21,627 | 18,533 | 15,325 | 12,044 |
| Soybean oil | 2,209 | 2,095 | 1,947 | 1,765 |
| Dicalcium phosphate | 1,060 | 1,082 | 1,105 | 1,129 |
| Limestone | 0,603 | 0,615 | 0,627 | 0,639 |
| Sodium bicarbonate | 0,179 | 0,336 | 0,499 | 0,612 |
| Salt | 0,292 | 0,186 | 0,076 | - |
| Premix[1] | 0,400 | 0,400 | 0,400 | 0,400 |
| L-Lysine HCl 78,0% | 0,309 | 0,408 | 0,510 | 0,615 |
| DL-Methionine 99,0% | 0,081 | 0,109 | 0,139 | 0,169 |
| L-Threonine 98.5% | 0,106 | 0,152 | 0,199 | 0,247 |
| L-Tryptophan 98,0% | 0,030 | 0,047 | 0,065 | 0,083 |
| L-Valine 98,0% | - | 0,028 | 0,087 | 0,147 |
| L-Isoleucine 100,0% | - | - | 0,026 | 0,086 |
| Antioxidant[2] | 0,010 | 0,010 | 0,010 | 0,010 |
| Growth promoter[3] | 0,020 | 0,020 | 0,020 | 0,020 |
| Calculated Composition % | | | | |
| Cálcium | 0,575 | 0,575 | 0,575 | 0,575 |
| Available phosphorus | 0,281 | 0,281 | 0,281 | 0,281 |
| Sodium | 0,176 | 0,176 | 0,176 | 0,176 |
| Potassium | 0,630 | 0,582 | 0,533 | 0,483 |
| Chlorine | 0,310 | 0,268 | 0,223 | 0,199 |
| SID lysine | 0,927 | 0,927 | 0,927 | 0,927 |
| SID methionine | 0,302 | 0,317 | 0,331 | 0,347 |
| SID met+cys | 0,574 | 0,547 | 0,547 | 0,547 |
| SID threonine | 0,603 | 0,603 | 0,603 | 0,603 |
| SID tryptophan | 0,185 | 0,185 | 0,185 | 0,185 |
| SID valine | 0,667 | 0,640 | 0,640 | 0,640 |
| SID isoleucina | 0,595 | 0,541 | 0,510 | 0,510 |
| SID histidine | 0,386 | 0,357 | 0,326 | 0,296 |
| SID phenilalanine | 0,697 | 0,643 | 0,586 | 0,529 |
| Metabolizable energy (kcal $kg^{-1}$) | 3350 | 3350 | 3350 | 3350 |
| Net energy (kcal $kg^{-1}$) | 2566 | 2581 | 2596 | 2611 |
| E. Balance (mEq $kg^{-1}$) | 150,02 | 150,03 | 150,01 | 143,89 |
| Ratio AAE:AANE | 45:55 | 46:54 | 46:54 | 47:53 |

[1]Premix should provide at least the following nutriente amounts per kg of feed:: vitamin A – 4000 UI; vitamin D3 – 600 UI; vitamin E – 12 UI; vitamin K3 – 3 mg; vitamin B1 – 0.6 mg; vitamin B2 - 3.5 mg; vitamin B6 – 1; vitamin B12 – 18 mg; niacin – 20 mg; pantothenic acid – 10 mg; folic acid – 1 mg; biotin - 0.03 mg; choline chloride – 0,16 g; iron – 35 mg; copper – 15 mg; manganese – 25 mg; zinc – 0.075 g; iodine – 1 mg; selenium 0.3 mg, [2]BHT; [3]leucomycin.

**Table 2.** Life cycle assessment, per kg of feed, in pig diets (50-70 kg), containing decreasing levels of crude protein (CP) and supplementation of synthetic amino acids

| | Crude protein (%) | | | |
|---|---|---|---|---|
| | 16 | 15 | 14 | 13 |
| | Soybean meal from South | | | |
| GWP, g $CO_2$-eq. | 411 | 425 | 443 | 464 |
| AP, g $SO_2$-eq. | 11,47 | 11,92 | 12,40 | 12,93 |
| EP, g $PO_4$-eq | 4,39 | 4,40 | 4,41 | 4,43 |
| CED, MJ-eq. | 5,18 | 5,47 | 5,89 | 6,38 |
| TE, g 1,4-DCB-eq. | 4,24 | 4,36 | 4,51 | 4,69 |
| LO, $m^2$-year | 1,04 | 1,01 | 0,98 | 0,96 |
| | Soybean meal from Midwest | | | |
| GWP, g $CO_2$-eq. | 712 | 683 | 657 | 632 |
| CED, MJ-eq. | 6,30 | 6,43 | 6,68 | 7,00 |

Global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), cumulative energy demand (CED), terrestrial ecotoxicity (TE) and land occupation (LO)

**Table 3.** Nitrogen and phosphorus balance of growing pigs (50-70 kg) fed diets with crude protein reduction and amino acids supplementation.

| | Crude protein (%) | | | | Standard error | ANOVA | P-value | |
|---|---|---|---|---|---|---|---|---|
| | 16 | 15 | 14 | 13 | | | Lin. | Quad. |
| N Intake ($g\ d^{-1}$) | 46,78±4,27 | 46,59±5,65 | 45,08±4,49 | 39,22±5,91 | 1,267 | 0,0214 | 0,002[1] | 0,2871 |
| N Feces ($g\ d^{-1}$) | 6,10±1,14 | 5,59±1,02 | 5,37±0,58 | 5,64±0,51 | 0,186 | 0,4522 | - | - |
| N Urine ($g\ d^{-1}$) | 13,33±4,27 | 12,85±2,06 | 10,16±2,11 | 9,32±0,92 | 0,527 | 0,0274 | 0,006[2] | 0,7595 |
| N Excreted ($g\ d^{-1}$) | 19,43±1,16 | 18,44±2,14 | 15,53±1,83 | 14,96±0,86 | 0,541 | 0,0036 | <0,001[3] | 0,8226 |
| N Retention (%) | 58,18±3,90 | 60,28±3,35 | 65,28±5,10 | 61,25±5,44 | 1,101 | 0,2168 | - | - |
| P Intake ($g\ d^{-1}$) | 8,81±0,59 | 8,90±1,08 | 9,26±0,89 | 7,93±1,19 | 0,244 | 0,1455 | - | - |
| P Feces ($g\ d^{-1}$) | 4,87±0,30 | 4,63±0,49 | 4,49±0,08 | 4,52±0,71 | 0,109 | 0,2990 | - | - |
| P Absorbed (%) | 44,44±6,03 | 47,81±4,09 | 51,06±5,96 | 42,88±6,06 | 1,405 | 0,1632 | - | - |

Linear effect[1] y= 9,31198+2,42113x($R^2$=0,89), Linear effect[2] y=-9,90543+1,47037x ($R^2$=0,88), Linear effect[3] y=-6,53338+1,62907 ($R^2$=0,93).

**Table 4.** Final weight, daily weight gain (DWG), feed conversion rate (FCR), daily feed intake (DFI), backfat thickness (BT), depth of *longissimus lumborum* (LL) muscle and plasma urea of growing pigs fed diets with crude protein reduction and amino acid supplementation.

| | Crude protein (%) | | | | Standard error | P-value | | |
|---|---|---|---|---|---|---|---|---|
| | 16,0 | 15,0 | 14,0 | 13,0 | | | Lin. | Quad. |
| Final weight, kg | 70,57±3,71 | 71,36±3,60 | 71,39±2,90 | 68,64±1,87 | 0,505 | 0,2529 | - | - |
| DWG, kg | 1,137±0,226 | 1,166±0,265 | 1,192±0,135 | 1,052±0,128 | 0,031 | 0,3794 | - | - |
| FCR, kg | 2,176±0,196 | 2,202±0,274 | 2,107±0,117 | 2,190±0,074 | 0,028 | 0,6396 | - | - |
| DFI, kg | 2,434±0,324 | 2,508±0,319 | 2,497±0,168 | 2,299±0,240 | 0,043 | 0,2336 | - | - |
| BT, cm | 0,975±0,094 | 0,939±0,133 | 0,955±0,114 | 0,956±0,246 | 0,017 | 0,9866 | - | - |
| LL, cm | 4,503±0,390 | 4,475±0,390 | 4,500±0,178 | 4,483±0,246 | 0,048 | 0,9961 | - | - |
| Urea mg $dL^{-1}$ | 33,50±5,61 | 28,45±7,91 | 25,67±6,77 | 20,94±7,83 | 1,300 | 0,0019 | P<0,001[1] | - |

Linear effect[1] y= -31,5122+4,04500 ($R^2$=0,99).

**Table 5.** Potential environmental impacts, per kg of body weght gain, of growing pigs from 50 to 70 kg, with crude protein reduction and amino acid supplementation.

| | Crude protein (%) | | | | *P*-value | | |
|---|---|---|---|---|---|---|---|
| | 16 | 15 | 14 | 13 | | Lin. | Quad. |
| | | | Soybean meal from South | | | | |
| GWP, kg $CO_2$-eq. | 3,01±0,28 | 3,05±0,38 | 2,93±0,16 | 3,06±0,11 | 0,6231 | - | - |
| AP, g $SO_2$-eq. | 41,41±3,75 | 40,83±5,07 | 37,91±2,10 | 40,68±1,37 | 0,1096 | - | - |
| EP, g $PO_4$-eq | 13,35±1,21 | 13,06±1,63 | 12,01±0,67 | 12,56±0,42 | 0,0510 | 0,036[1] | 0,124 |
| CED, MJ-eq. | 17,88±2,20 | 18,52±2,39 | 18,86±1,41 | 21,33±1,91 | 0,0032 | <0,001[2] | 0,156 |
| TE, g 1,4-DCB eq. | 12,29±1,15 | 12,80±1,64 | 12,41±0,71 | 13,31±0,46 | 0,1647 | - | - |
| LO, $m^2$-year | 2,26±0,20 | 2,22±0,28 | 2,06±0,11 | 2,10±0,07 | 0,0632 | 0,019[3] | 0,517 |
| | | | Soybean meal from Midwest | | | | |
| GWP, kg $CO_2$-eq. | 3,67±0,33 | 3,62±0,45 | 3,38±0,19 | 3,43±0,12 | 0,1005 | - | - |
| CED, MJ-eq. | 20,31±2,40 | 20,64±2,64 | 20,53±1,49 | 22,69±1,23 | 0,0440 | 0,028[4] | 0,185 |

Linear effect[1] y= 8,02464+0,322171x ($R^2$=0,55)**,** Linear effect[2] y= 34,6684-1,07034x ($R^2$=0,84)**,** Linear effect[3] y= 1,24218+0,063535x ($R^2$=0,76)**,** Linear effect[4] y= 31,2237-0,702253x ($R^2$=0,67)**)**

# V-CONSIDERAÇÕES FINAIS

Este trabalho teve como diferencial avaliar o impacto ambiental da produção de suínos nas fases de crescimento, 30-50 kg e de 50-70 kg, utilizando-se a ACV. Os dados obtidos nos experimentos de desempenho e metabolismo demostram a importância destas avaliações quando alguma alteração é realizada na dieta dos animais, mesmo que todas as exigências sejam atendidas.

Embora se tenha feito as correções necessárias nas inclusões dos aminoácidos em dietas com níveis decrescentes de proteína foi observado que os animais apresentaram respostas divergentes entre as fases de 30-50 kg e 50-70 kg, uma vez que, para os animais de 30-50 kg o decréscimo dos níveis proteicos promoveram melhora no ganho de peso dos animais, porém este resultado não foi observado para os animais de 50-70 kg. Estes resultados demostram a importância da avalição a campo quando se tem por objetivo avaliar o impacto ambiental de dietas distintas, já que assim como os dados referentes a produção das dietas, o aproveitamento dos nutrientes pelos animais, a excreção deste nutrientes, e o desempenho, tem extrema relevância para que esta avaliação seja realizada de forma precisa.

Conclui-se que a redução da proteína bruta e suplementação de aminoácidos industriais em dietas para suínos em crescimento (30 - 50 kg) reduziu os impactos ambientais para as categorias acidificação, eutrofização e ocupação de terra, contudo para suínos em crescimento (50 – 70 kg) a redução proteica promoveu menor impacto para as categorias potencial de eutrofização e ocupação de terra, porém, para a demanda acumulada de energia o efeito foi oposto, tanto para a análise realizada utilizando-se a soja produzida na região sul quanto a produzida na região centro-oeste.