Nutrient utilization with and without recycling within farming systems

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Abstract

Nutrient balances are used as a measure of nutrient utilization. It is, however, difficult to compare the nutrient utilization between farms, especially if their production systems are different. New analytical tools and methods of interpreting nutrient utilization based on nutrient balances are introduced.

Nutrients are divided into primary nutrients (f, any external nutrient input into primary production) and secondary nutrients (m, any internal nutrient input into primary production). Primary production, Y, is a result of primary and secondary nutrients: $Y = p(f+m)$ where p = utilization rate of nutrients. The definition of utilization rate of nutrients is the same as that of surface balance. Since surface balance does not provide any information about recycling nutrients, the term circulation factor ($e = (f+m)/f$) is introduced.

Finally, two new tools of measuring nutrient utilization have been introduced. These are primary production balance (N) and internal gate balance (I). Primary production balance ($N = p*e$) indicates the amount of primary production per unit of primary nutrient in any given system. All food production is based on primary production. Primary production can be used directly by humans or converted into animal products. The primary production balance is independent of usage of primary production and comparison between any farm independent of production type is possible.

Unlike farm gate balance (G), the internal gate balance ($I = N * H$, where H is cattle balance) is also independent of the origin and quality of nutrients. It indicates the nutrient utilization within any given system. It is also not sensitive to the production system.

Introduction

Nutrient balance is used as a measure of nutrient utilization. The most used nutrient balances are:

CATTLE BALANCE (H)	=	ANIMAL PRODUCTS / FEED
SURFACE BALANCE (S)	=	HARVESTED YIELD / NUTRIENT INPUT
FARM GATE BALANCE (G)	=	OUTPUT / INPUT

There are, however, some difficulties in comparing nutrient utilization between farms, especially if their production type is different. According to Myrbeck (1999), the farms should be divided into an animal production part and a plant production part. This would increase the usefulness of nutrient balance as an instrument for evaluating operations at farm level and for comparing nutrient utilization between different farming systems. In this paper I introduce some analytical tools and methods of interpreting nutrient utilization based on nutrient balances. Some numerical examples are given to elucidate the ideas. If the ten hypothetical farms listed in Table 1 were ranked from the best to the worst, various answers could be given.

List of symbols (new tools **bold**):

Balances:

G, farm gate balance = output/input

H, cattle balance = animal products/feed

S, surface balance = harvested yield/nutrient input

N, primary production balance (N = p*e)

I, internal gate balance (I = H*N)

Inputs & outputs:

B, purchased feed

F, purchased fertilizer

M, manure

P, total nutrient input (into primary production)

Y, yield (harvested crop, primary production)

A, animal production (secondary production)

Additional terms:

a, utilization rate of feed (a=A/(Y+B))

p, utilization rate of nutrients (equal to surface balance, p = Y/(f+m)

f, primary nutrient (external nutrient input into primary production)

m, secondary nutrient (internal nutrient input, i.e. recycling nutrient)

e, circulation factor (e = (f+m)/f)

y, relative yield (y = Y/f)

Table 1 Nutrient utilization on ten hypothetical farms

	INPUTS		OUTPUTS			BALANCES		
	Fertilizer (F)	Feed (B)	Manure (M)	Crop (Y)	Animal (A)	Cattle (H)	Surface (S)	Farm gate (G)
Farm								
1	100	-	-	80	-	-	0.8	0.8
2	-	80	(64)	-	16	0.2	-	0.2
3	100	-	64	80	16	0.2	0.49	0.16
4	100	-	-	50	-	-	0.5	0.5
5	100	-	40	50	10	0.2	0.36	0.1
6	50	50	80	50	20	0.2	0.38	0.2
7	-	100	118	50	32	0.21	0.42	0.32
8	100	-	90	100	10	0.1	0.53	0.1
9	100	-	120	150	30	0.2	0.68	0.3
10	100	-	153	170	17	0.1	0.67	0.17

Figures are given without any units (i.e. the figures indicate amounts of nutrients and are commensurable). Note: If both crop and animal products are produced only animal products are sold;crop is always used to feed the animals on the farm! Please rank the farms from the best to the worst!

Primary production, secondary production - primary nutrients, secondary nutrients

Farms 1-3 form a special group. Farm 1 specializes in crop production; only crop products are sold without any recycling of nutrients. Farm 2 specializes in animal production with no crop production. Therefore, the surface balance cannot be determined and manure is not used for anything (it is neither sold nor used on the farm). Farm 3 integrates the productions of Farms 1 and 2.

As we can see, the farm gate balance is better on Farms 1 and 2 compared to Farm 3, even when the inputs and outputs on Farm 3 are equal to those on Farms 1 and 2 together. It is obvious that the farm gate balance is not a commensurable indicator of nutrient utilization.

The following equation is valid for Farms 1 and 2:

(1) Y = pF, where Y = primary production, ***p = utilization rate of nutrients***, F = purchased fertilizer (i.e. nutrient input)

(2) A = aY, where A = secondary production (animal production), a = utilization rate of feed

However, the animal production (secondary production) system produces manure (M), which can be recycled in the system. The amount of manure is (theoretically):

M = Y - A

On Farm (3), yield (Y) was obtained not only because of nutrient input (F) but also due to additional manure nutrient input (M = Y-A). To separate these two nutrient inputs, any external nutrient input into the primary production is called ***primary nutrient (f)*** and any internal nutrient input (i.e. recycling nutrient)

into the primary production ***secondary nutrient (m).*** Hence, the total amount of nutrients available, P, (i.e. nutrient input on the field) is:

$P = f + m$

which gives the final equation for Farm 3:
(3) $Y = p(f + m)$

Both sides of the equation can be divided by f as follows:
(3) $y = p(f + m)/f$, where $y = Y/f$ (relative yield).

The term $(f + m)/f$ is designated as ***circulation factor (e) and equation y = p*e as primary nutrient balance (N).***

Comparison between Farms 1 and 3 shows the difference in nutrient utilization:
(1) $y = p$, *yield is dependent only on the utilization rate of nutrients (p) in any system without recycling*

(3) $y = p*e$, *yield is dependent on the utilization rate of nutrients (p) and the circulation factor (e) in any system with recycling*

Circulation factor, e = (f+m)/f

Definition: the circulation factor (e) indicates how much recycled nutrients (= secondary nutrients) are utilized in the primary production of a farm.

Value $e = 1.0$ indicates no circulation, values higher than 1.0 indicate circulation. As we can see, on the crop farm without secondary production the value of the circulation factor is always 1. If manure is produced on the farm, the circulation factor is always higher than 1. In theory there is no upper limit. In any natural ecosystem (in practice closed systems) very high values of e can be found ($e > 10$), but in agricultural ecosystems values higher than 2 are unlikely.

There are no problems in calculating circulation factors for the systems where only fertilizers are purchased. In these systems fertilizers equal the amount of primary nutrients (f), and manure produced on the farm equals the amount of secondary nutrients (m).

Whenever feed is purchased into the farm it is more difficult to calculate the primary and secondary nutrients. By definition feed itself is not a primary nutrient since it is not used for primary production. However, any manure produced from purchased feed is primary nutrient. On the other hand, all the manure-originated crop produced on the farm is secondary nutrient. Farms 6 and 7 purchase some feed (Table 1). The primary nutrients on Farm 6 comprise 50 units from fertilizers and 40 units from purchased feed (10 units are sold as secondary products and never reach the primary production system on the farm). Secondary nutrients comprise 40 units from crop produced on the farm (10 units are sold as secondary products).

The circulation factor for Farm 6 is: $e = (50 + 40 + 40)/(50 + 40) \cong 1.44$

According to the same principle the circulation for Farm 7 is: $e \cong (0 + 79 + 39)/(0 + 79) \cong 1.49$

Utilization rate of nutrients, p

Definition: the utilization rate of nutrients (p) indicates the proportion of nutrients taken up by crop and harvested in the primary production.

In fact, the definition of p is the same as that of the surface balance (S), which means that they are equal. Most often p varies between 0 and 1, but values higher than 1 are possible. If p is higher than 1, nutrients are taken from the soil, either from the organic (decomposition of organic material) or inorganic pool (weathering of minerals).

The utilization rate does not give any direct information about recycling. Farms 1 and 4 have the highest utilization rates (surface balance) even in the absence of recycling .

Primary production balance, N = p*e

Definition: the primary production balance shows how much primary production is produced per unit of primary nutrients in any given system.

All food production is based on primary production. Only primary products can be converted into food, including animal products. From the ecological point of view animal production is not production at all, it is only one way of consuming primary production (another choice is to use primary production directly by humans). That is why the primary production balance completes the picture of nutrient utilization.

The final efficiency of nutrient utilization in agriculture is determined by two components, utilization rate of nutrients and circulation factor. There is still another choice to be made, either to use the primary production by humans or to process it into animal products. Some primary products are not, however, suitable for human consumption and in such instances there is no real choice available. As long as there is a real choice between crop production and animal production we have to keep in mind that crop production always needs less resources and has less negative environmental impacts than the same amount (energy or nutrients) of animal products. In case there is no recycling between these two processes, the rate of converting primary products into secondary products varies widely between 0.1 and 0.5. These conversion rates indicate roughly the need of resources and environmental impacts in the secondary production compared to the primary production, i.e. 5 to 10-fold the amount of crop products.

The only way of reducing the need of resources and cutting the environmental impacts in secondary production (and in the whole food production process) is to integrate these two processes.

The maximum value in the long run for the primary production balance in any system without recycling is 1.0. Values higher than 1.0 are possible only with recycling, i.e. crop production is integrated with animal production. Another integration partner to crop production could be the community. Please note that the circulation factor has no upper limit!

Primary production balance vs. other balances

The weakness of the farm gate balance is easy to understand either with Farms 1 – 3 or Farms 5 and 6. Farms 5 and 6 are identical in terms of quantity but not quality of inputs. On Farm 5 the inputs comprise 100 units of fertilizers (primary nutrients) and on Farm 6 50 units of fertilizers and 50 units of feed

(equals 40 units of primary nutrients in crop production). This is the main reason why the traditional farm gate balance is not a commensurable indicator of nutrient utilization.

If only primary nutrients are input, all the primary nutrients are used for primary production, all the primary production is used to feed the animals and only animal products are sold, the equation would be:
Cattle balance * Primary production balance = Farm gate balance (H * N = G)
But as soon as any of these conditions is not valid, H * n results in a value different from G. However, the primary production balance indicates in any condition how much primary production is produced in any given system by one unit of primary nutrients. Cattle balance is analogous to primary production balance; it shows how much secondary production is produced in any given system by one unit of primary production. Thus, primary production balance multiplied by cattle balance indicates the utilization of nutrients within any given system. This new indicator can be called internal gate balance (I):

I = N * H

Comparing different farms with new tools

Table 2 Nutrient utilization on ten hypothetical farms.

	INPUTS		OUTPUTS			BALANCES					
	Fertil	Feed	Manure	Crop	Animal	Cattle	Surface (p)	Farm gate	Circulation Primary factor e =(P+M)/P e =(f+m)/f	Internal Production balance N=p*e	Gate balance (I=N*H)
Farm	(P)	(B)	(M)	(Y)	(A)	(H)	(S)	(G)			
1	100	-	-	80	-	-	0.8	0.8	1.0		0.8
2	-	80	(64)	-	16	0.2	-	0.2	-		- -
3	100	-	64	80	16	0.2		0.16	1.64	0.8	0.16
							0.49				
4	100	-	-	50	-	-	0.5	0.5	1.0		0.5
5	100	-	40	50	10	0.2	0.36	0.1	1.4	0.5	0.1
6	50	50	80	50	20	0.2	0.38	0.2	1.44	0.56	0.11
7	-	100	118	50	32		0.42	0.32	1.49	0.62	0.13
						0.21					
8	100	-	90	100	10	0.1	0.53	0.1	1.9	1.0	0.1
9	100	-	120	150	30	0.2	0.68	0.3	2.2	1.5	0.3
10	100	-	153	170	17	0.1	0.67	0.17	2.53	1.7	0.17

The figures are given without any units (i.e. figures indicate amounts of nutrients and are commensurable). Note: If both crop and animal products are produced only animal products are sold; crop is always used to feed the animals on the farm! Besides traditional nutrient balances (cattle, surface, and farm gate) new indicators and tools (utilization rate of nutrients (p equal to surface balance, S), circulation factor (e) and primary production balance (N = p*e)) have been introduced. What is the minimum amount of primary nutrients needed to produce 32 units of animal products and which farm is capable of doing it?

Solution with the old nutrient balance method:

Farm 1 has the highest surface balance and Farm 7 has the highest cattle balance. Would it be possible to produce feed on Farm 1 and animal products on Farm 7 with the highest possible utilization rate of nutrients? To produce 32 units of animal products on these two farms, 125 units of primary nutrients are needed.

Solution with the new method:

Primary nutrient balance (N) shows how much yield (feed) can be produced by unit of primary nutrient. The highest value of N is 1.7 on Farm 10, but the cattle balance is very poor on Farm 10, 0.1. The internal gate balance is 1.7 * 0.1 = 0.17, which is the second highest. The highest internal gate balance is on Farm 9, 1.5 * 0.2 = 0.3. Thus, if only primary products were needed, farm 10 is the best choice, but if the final products must be animal products, Farm 9 is the most effective one (about 107 units of primary nutrients are needed to produce 32 units of animal products).

References

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