Effect of weed control methods on some soil properties of a newly planted cocoa farm

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ABSTRACT

Weed control constitutes a high percentage of the total field maintenance cost of newly planted cocoa. Soil samples were collected from an experiment that was designed to evaluate some weed control methods during cocoa establishment. The objective of the experiment was to assess the effect of the weed control methods on microbial biomass and extractable N and P contents of the cocoa-growing soil during cocoa establishment. The weed control treatments were clean weeding, two times per year; clean weeding, three times per year; clean weeding, four times per year (recommended practice); high slashing, four times per year; clean weeding (1 m wide), three times per year plus *Mucuna pruriens* cover crop; clean weeding, three times per year plus *Flemingia congesta* mulch; Gramoxone 1.5 l ha^{-1}, four times per year; and Roundup 1.5 l ha^{-1}, three times per year arranged in a randomized complete block design. Microbial biomass N content ranged from 10.8 to 42.5 mg N kg^{-1} soil. Microbial biomass N was significantly higher (P<0.01) in the clean weeding two times per year plot than in the other treatments. Microbial biomass P content ranged from 3.2 to 9.2 mg P kg^{-1} soil. The clean weeding two times per year plot recorded significantly higher (P<0.01) values for microbial biomass P among the treatments. Microbial biomass content was lower in the clean weeding four times per year, Gramoxone and Roundup plots. Extractable N and P contents of the soils differed significantly between the treatments. Extractable N and P contents ranged from 282.6 to 712.8 mg N kg^{-1} soil and from 8.4 to 17.5 mg P kg^{-1} soil, respectively. The lowest amounts of the extractable nutrients were found in the clean weeding two times per year plot, while higher values were recorded in the herbicide-treated plots. The lowest amounts of extractable N and P coincided with the highest contents of microbial biomass in the soils, more especially in the clean weeding two times per year plot. Herbicide application and inclusion of legumes in the weed control methods resulted in lower microbial N/P ratios. It is, therefore, concluded that more frequent weeding of three to four times per year and the use of herbicides could improve the availability of N and P for cocoa uptake.

RÉSUMÉ

OFORI-FRIMPONG, K., AFRIFA, A. A., OPPONG, F. K. & APPIAH, M. R.: *Effet de méthodes de maîtrise de mauvaise herbe sur quelques propriétés de sol d'un champ de cacao nouvellement planté.* La maîtrise de mauvaise herbe constitue un grand pourcentage de frais total d'entretien sur le terrain de cacao nouvellement planté. Les échantillons de sol étaient obtenus d'une expérience qui était destinée à évaluer quelques méthodes de maîtrise de mauvaise herbe pendant la plantation de cacao. Le but de cette expérience était d'estimer les effets de méthodes de maîtrise de mauvaise herbe sur la biomasse microbienne et les teneurs en N et P extractibles du sol de la culture cacao pendant la plantation de cacao. Les traitements pour la maîtrise de mauvaise herbe étaient: le désherbage propre deux fois/an; le désherbage propre trois fois/an; le désherbage propre quatre fois/an (lapratique recommandée); l'entaillage élevé quatre fois/an; le désherbage propre (1m large), trois fois/an plus une culture de couverture *Mucuna pruriens;* le désherbage propre trois fois/an plus une paillis de *Flemingia congesta*; Gramoxone 1.51/ha, quatre fois/an; et le produit chimique "Roundup" 1.51/ha, trois fois/an arrangé dans un dessin de bloc complet choisi au hasard. La teneur de N de la biomasse microbienne variait entre 10.8 et 42.5 mg N kg^{-1} de sol. Le N de la masse microbienne était considérablement plus élevé *(P*< 0.01) sur le lot de désherbage propre deux fois/an que sur les autres traitements. La teneur en P de la biomasse microbienne variait de 3.2 à 9.2 mg P kg^{-1} de sol. Le lot de désherbage deux fois/an donnait les valeurs considérablement plus élevées (P< 0.01) pour le P de biomasse microbienne parmi les traitements. La teneur en biomasse microbienne était plus faible sur les lots de désherbage propre quatre fois/an, de Gramoxone et de "Roundup". Les teneurs en N et P extractibles de sols différaient considérablement entre les traitements. Les teneurs en N et P extractibles variaient respectivement entre 282.6 et 712.8 mg N kg^{-1} de sol et entre 8.4 et 17.5 mg P kg^{-1} de sol. Les moindres quantités de nutriments extractibles étaient observées sur le lot de désherbage propre deux fois/an alors que les valeurs plus élevées étaient enregistrées sur les lots traités de herbicide. Les moindres quantités de N et P extractibles coïncidaient avec les teneurs les plus élevées en biomasse microbienne

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dans les sols d'autant plus sur le lot de désherbage propre deux fois/an. Application de herbicides et l'inclusion de légumineuse dans les méthodes de maîtrise de mauvaise herbe entraînaient les proportions de N/P de microbien plus faible. La conclusion est donc tirée que le désherbage plus fréquent de trois à quatre fois/an et usage de herbicides pourraient améliorer la disponibilité de N et P pour absorption par le cacao.

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Introduction

Cocoa cultivation in Ghana is now concentrated mainly in areas with secondary bushes and on land carrying old and moribund cocoa. The soils on such lands are very low in nutrients. Such areas also experience high rainfall and temperature which promote rapid weed growth and regeneration. Frequent weeding is, therefore, necessary to check competition for growth resources between the cocoa and the weeds, especially during cocoa establishment.

Earlier results of weed control in cocoa at the Cocoa Research Institute of Ghana (CRIG) have indicated that superior growth and yield of cocoa are associated with the use of herbicides such as paraquat and glyphosate compared with manual weed control (Bonaparte, 1981a, 1981b; Brown & Boateng, 1972). Similarly, higher yields of coffee were observed in plots in which paraquat was applied than in plots that had the weeds slashed six times in a year (Ampofo, Afrifa & Tabiri, 1987). Bonaparte (1981b) showed that it was economical to use paraquat for weed control in newly planted cocoa. However, the high cost of herbicides may not encourage farmers to adopt the technology. The rural-urban migration of the youth also limits manual weed control.

The CRIG is now evaluating cost-effective methods of controlling weeds in newly planted cocoa. Such methods include manual weeding at different number of times in a year, the use of some annual and herbaceous legumes as live mulch and their prunings as mulch materials, and also the use of herbicides. Applying these weed control methods may have direct or indirect effects on the soil, and may influence the growth and activity of soil organisms that are responsible for most biochemical transformations in the soil. For example, the levels of organic and inorganic N and P in soils are influenced largely by the activities of soil microbes so that any change in microbial activity is likely to influence the availability of the nutrients.

Better weed control and improvement in some soil properties were recorded by using leguminous plants in newly planted cocoa (Ofori-Frimpong *et al.*, 2000). Fening & Odamtten (1992) reported a minimal side effect of paraquat on soil microbial population when it was applied at the recommended field rates on some cocoa-growing soils. An increased mineralization of nitrogen has been observed in Roundup-treated soil. Until recently, the soil has been the main source of nutrient supply to cocoa in Ghana, with the release of nutrients (particularly N and P from organic matter) depending on the activity of soil micro-organisms. The soil microbial biomass is a relatively labile constituent of soil organic matter (Jenkinson & Ladd, 1981).

It would, therefore, be necessary to assess the effects of the cost-effective weed control methods being evaluated at CRIG on soil properties.

This study seeks to measure the microbial biomass and extractable N and P contents of a cocoa-growing soil under different weed control methods to assess the weed control methods on N and P availability in cocoa-growing soils.

Materials and methods

The Cocoa Research Institute of Ghana's sub-station in Bunso on an Acrisol was used for the study. The soil has been classified as Ferric Lixisol

(FAO/UNESCO, 1990). The original experiment was to evaluate eight different methods of controlling weeds in newly planted cocoa in a randomized complete block design with five replications. The trial, which was established in 1993, has the following weed control treatments:

T1: Clean weeding, two times per year
T2: Clean weeding, three times per year
T3: Clean weeding, four times per year
T4: High slashing, four times per year
T5: Clean weeding (1m wide) of cocoa lines two times per year plus *Mucuna pruriens* cover crops planted in the inter-rows
T6: Clean weeding of cocoa lines three times per year plus *Flemingia congesta* planted in the inter-rows to be used as mulch
T7: Gramoxone applied at 1.5 l ha^{-1} in 300 l ha^{-1} of water, four times per year
T8: Roundup applied at 1.5 l ha^{-1} in 100 l ha^{-1} of water, three times per year

Soil sampling and analytical methods

Soil samples were taken from three replicates of each treatment plot at 0.15 cm depth in September 2000. All samples were immediately sieved through 2.0-mm mesh and stored in plastic bags at 4 °C.

Measurement of microbial biomass N and P

The fumigation-extraction method of Jenkinson & Ladd (1981) was used. Moist sub-samples were placed in a desiccator containing alcohol-free chloroform. The desiccator was evacuated until chloroform had boiled for 5 min and was then kept for 24 h. The chloroform vapour was removed by repeated evacuation.

Biomass N and P were determined by extracting the fumigated soil samples with 0.5*M* K_2SO_4 and 0.5*M* $NaHCO_3$ solutions, respectively. The non-fumigated sub-samples were also extracted by the same method. The extracts were either analysed per for total N after Kjeldahl digestion or analysed for total P after digesting in 70 per cent $HC1O_4$. Biomass N and P were determined as the difference between the extracted N and P in the fumigated and non-fumigated soils, divided by an assumed factor to account for the fraction of the biomass N and P that is considered to be extracted. For biomass N, a factor of 0.54 was used (Brookes *et al.*, 1985); and for biomass P, a factor of 0.4 was used (Brookes, Powlson & Jenkinson, 1982).

Measurement of extractable N and P

A moist sub-sample was shaken with 1*M* KC1 solution for 60 min and filtered through a Whatman No. 42 paper (Bremner & Keeney, 1965). The filtrate was analysed for NH_4^+ and NO_3^- after steam distillation (Bremner, 1965). For the extractable P, a moist sub-sample was shaken with 0.5 *M* $NaHCO_3$ solution at *p*H 8.5 for 30 min, filtered through a Whatman No. 42 paper, and the P determined by the ammonium molybdate-ascorbic acid method (Murphy & Riley, 1962).

Statistical analyses

The ANOVA was performed on the data. The means were compared by the Least Significant Difference test.

Results

Table 1 presents some soil properties of the soil used for the experiment. Based on the properties, the soil from the site is classified as suitable for cocoa cultivation. Table 2 presents the effects of the weed control methods on microbial biomass and extractable N and P contents of the soil. Microbial biomass N content ranged from 18.7 to 49.5 mg N kg^{-1} soil, with a mean value of 26.5 mg N kg^{-1} soil. Microbial biomass N was significantly higher ($P<0.01$) in the clean weeding two times per year plot, and lowest in the Gramoxone 1.5 l ha^{-1} four times per year and Roundup 1.5 l ha^{-1} three times per year plots. Microbial biomass P content ranged from 4.2 to 9.2 mg P kg^{-1} soil, with a mean value of 6.4 mg P kg^{-1} soil. Microbial biomass P was significantly lower ($P<0.01$) in the clean weeding four times per year, Gramoxone and Roundup plots. The highest value of biomass P was recorded in the clean weeding two times

TABLE 1

Some Soil Properties of the Soil Used for the Experiment (0-15 cm)

p*H* (1:2.5 H_2O)	*C* (%)	*Total N* (%)	*Available P* (µg g^{-1} soil)	*Exch. K* (cmol (+) kg^{-1})
6.3	2.0	0.17	12.4	0.224

TABLE 2

Effect of Weed Control Methods on Soil Properties

Treatment	*Microbial biomass* N (mg N kg^{-1})	*Microbial biomass* P (mg P kg^{-1})	*Extractable* N (mg N kg^{-1})	*Extractable* P (mg P kg^{-1})	*Microbial* N / P
Clean weeding, 2 times/year	42.5a +	9.2a	282.6d	8.4c	4.6a
Clean weeding, 3 times/year	28.4b	6.0b	371.8cd	12.9b	4.7a
Clean weeding, 4 times/year	15.6cd	4.2b	613.7ab	17.5a	4.9a
High slashing, 4 times/year	30.8b	6.6a	434.2c	9.8bc	4.6a
Clean weeding (1 m wide) 2 times/year + Mucuna	18.7c	7.5a	584.6b	12.3b	2.5b
Clean weeding 2 times/year + *Flemingia* mulch	22.9c	7.8a	540.8b	11.8b	2.9b
Gramoxone, 1.5 l ha^{-1}, 4 times/year	10.8d	4.5b	712.8a	13.8a	2.4b
Roundup 1.5 l ha^{-1}, 3 times/year	12.2d	5.2b	694.5a	16.6a	2.3b
LSD (0.05)	7.5	2.7	102.3	3.8	1.2

+ Means with the same letter in the same column are not significantly different

per year plot. Considering all the manual weed control methods, the highest microbial biomass content was recorded in the clean weeding two times per year plot. Adding legumes to the weed control methods reduced the microbial biomass content compared with the clean weeding two times per year without the legumes. However, the herbicide treatments recorded the lowest biomass contents.

The extractable N contents of the plots ranged from 282.6 to 712.8 mg N kg^{-1} soil, with a mean value of 529.4 mg N kg^{-1} soil. The differences in the extractable N contents of the plots were significant (P<0.05). The lowest and highest values were recorded in the clean weeding two times per year and Gramoxone plots, respectively. The extractable P contents of the plots ranged from 8.4 to 17.5 mg P kg^{-1} soil, with a mean value of 12.9 mg P kg^{-1} soil. The clean weeding four times per year plot recorded significantly higher (P<0.01) extractable P content among the treatments. Adding legumes to the weed control methods increased the extractable N contents of the soils, but did not significantly improve the extractable P contents of the soils when compared with the recommended practice of clean weeding four times per year. The relationships between microbial biomass N and extractable N (r = + 0.962), and microbial biomass P and extractable P (r = -0.842) were significant (P<0.01). Microbial N / P ratios were also significantly higher (P<0.05) in manual weed control methods without the legumes.

Discussion

In Ghanaian cocoa-growing soils, nitrogen and phosphorus available to cocoa tend to be tied up to organic matter (Ahenkorah, 1968) and most of the total P is in organic form (Acquaye, 1963;

Appiah, 1975). Microbial activity is, therefore, being implicated as the major determinant in the nutrient-release and immobilization processes in such soils. The soil microbial biomass is known to be actively involved in the decomposition and turnover of organic matter in soils.

In this study, higher microbial biomass N and P contents were recorded in clean weeding two times per year. Similarly, extractable N and P levels were lower in the clean weeding two times per year plot. Less frequent weed control, as with clean weeding two times per year, could result in increased uptake of N and P by cocoa and the weeds which might reduce their concentrations in the soil. The release of N and P from soil organic matter is microbially mediated. Lower concentrations of the nutrients in the soil could, therefore, lead to the microbial population depending on the products of organic matter mineralization; hence, the higher microbial biomass content of the clean weeding two times per year plot.

The effects on N and P transformations of adding inorganic N and P to soil include net mineralization. *Mucuna pruriens* and *Flemingia congesta* are legumes that can fix nitrogen into the soil. Gramoxone and Roundup have nitrogen and phosphate ions in their structures. Probably the lower microbial biomass and higher extractable N and P observed in these plots were due to the N and P added to the soil from other sources which may have satisfied the nutrient requirements of the microbes; and, hence, the lower nutrient assimilation by the microbes.

The lower biomass contents of the clean weeding four times per year, Gramoxone and Roundup plots as well as their higher contents of extractable N and P may be explained by the better weed control recorded by the methods; and, thus, eliminating competition for the nutrients between cocoa and weeds. It is also possible that more trash added to the soil by these methods could increase the soil organic matter content; hence, an increased mineralization of the nutrients.

The significant positive and negative correlations between microbial biomass and extractable N and P, respectively, suggest that N mineralization is not closely linked to organic P mineralization as proposed by McGill & Cole (1981). The higher microbial N / P ratios in the manual weed control methods without the legumes suggest the need to include N fertilizers in manual weed control methods that would be adopted on newly planted cocoa farms.

Conclusion

Clean weeding two times per year resulted in higher microbial biomass and lower extractable N and P contents of the soil compared with the more frequent weeding and the herbicide treatments. Less frequent weeding could, therefore, result in increased nutrient uptake by cocoa and the weeds, thereby resulting in the soil microbes depending on the products of organic matter decomposition. Adding nutrients, particularly N and P, to the weed control methods during cocoa establishment could increase the availability of the nutrients for cocoa uptake and reduce the microbial uptake of the nutrients.

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