PROBLEMS AND PROSPECTS OF FERTILISER USE IN PLANTATION FORESTRY IN THE TROPICS

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ABSTRACT
Regular use of forest lands by man, poor forest management and harvesting of forest products leads to loss of soil nutrients and decreased soil fertility. Organic and mostly inorganic fertiliser uses in forestry to correct these nutrient losses pose many environmental problems. This paper attempts to highlight the problems inherent in fertiliser use in forest plantations as well as prospects for mitigating the problems. Generally, fertiliser use increases and maintains productivity in forest plantations; prolonged fertiliser use however produces some unpalatable non-target effects such as: boosting or decreasing the populations of decomposer organisms (micro-flora and micro-fauna); production of nitrous oxide, methane, ammonia and carbon dioxide gases which are greenhouse gases implicated in global warming; pollution of drinking water; promotion of nutrient antagonism. Nutrient requirement in forests can be minimised through good forest management practices such as; debarking the tress in situ at the forest site to reduce nutrients removed during tree harvest; biological nitrogen fixation by planting leguminous trees or shrubs in plantations; breeding plant components that influence uptake of nutrients by trees. Waste materials can be incorporated or blended with inorganic fertiliser to reduce the high cost and adverse effects of inorganic forest fertilisation.

INTRODUCTION

Fertilisers are compounds applied to plants to promote growth (Wikipedia, 2007). They are usually supplied either via the soil for uptake by plants roots or by foliar feeding or through leaves. Fertilisers applied to forest plantations may be organic or inorganic in nature. They can be naturally-occurring compounds (such as peat or mineral deposits) or manufactured through natural processes (like composting) or chemical processes such as the Haber process (Discover Magazine, 2006).

Fertilisers typically provide the three major plant nutrients (nitrogen, phosphorus and potassium), the secondary plant nutrients (calcium, sulphur, magnesium) and the trace elements (boron, chlorine, manganese, iron, zinc, copper and molybdenum) with a role in plant nutrition (Nwoboshi; 2000; Wikipedia, 2007). Formerly, both organic and inorganic fertilisers were called “manures”, but this term is now mostly restricted to man-made manure.

Chemical synthesis of fertilizer has since its discovery remained one of the main methods of correcting nutrient deficiencies in agriculture and forestry. From about 1960, when it was first tried as a large-scale silvicultural operation in the United States, forest fertilisation has received global application. The current level of application stands around one million hectares per annum (Nwoboshi, 2000).

The conversion of forests to high-yielding, shorter-rotation plantation systems, and the use of chemical fertilisers to improve the growth of forest stands will increasingly become an accepted cultural practice. Practices like clear-felling, and more intensive utilisation of biomass reduce natural soil fertility (Nwoboshi, 1982), or further impoverish the usually infertile sites where forest tree crops are and will increasingly be relegated to in future. Fertiliser additions become necessary to maintain site quality and productivity. The current and future forest nutritional management objectives will extend beyond correcting nutrient deficiencies, causing significant economic levels of tree mortality, deformity or loss of growth potential. These measures will include: (1) Replacing nutrient losses through harvesting, leaching, volatisation etc. from the production system. (2) Maximising economic benefits associated with thinning and (3) Optimising resource production rates on sites where nutrient levels potentially limit grow.

Effective use of fertilisers in forestry must, be based on sound scientific and economic considerations required to answers questions like: what fertiliser carriers to use, when, how much, how often to apply them and by what method, what fertiliser treatments have the most favourable cost-benefit potential for the specific forest stand and site condition. This review attempts to answer these questions to arrive at the most appropriate decisions under given prevailing environmental site conditions.

METHODS OF FERTILISER APPLICATION:

The methods devised and used in fertilisation of forest plantations are broadly classified into: - seed coating and seedling soaking in nutrients, mixing with growing medium, broadcasting, localised placement and spraying. Pre-sowing seed coating and pre-planting soaking of seedlings in nutrients have been widely used in agronomy and have promise of successful application in forest plantations. Cu, Mn, Zn and B have been used to improve germination of seeds in some species, while copper sulphate solutions similarly improve seedling growth.

Dry fertilisers may be directly applied to the growth medium before sowing or planting. Fertiliser may be applied with the potting medium for containerised seedlings or incorporated in nursery beds for bare-rooted seedlings. This method of application is costly, requiring mixing of different fertilisers and pot medium for different stages of seedling growth. Mixing incompatible fertiliser compounds, for example, may be problematic as follows: if ammonium or urea N-fertiliser is added to a limed soil, ammonia gas will be formed and most of it may be lost. Similarly, mixing lime with ammonium phosphates, super-phosphates or any fertiliser containing P will make all or most of the P insoluble and unavailable (Nwoboshi, 2000).

Broadcasting evenly spreads the fertiliser over the soil and to incorporate them into part of the top soil. This method gives the best distribution of fertiliser to root systems, especially in the nursery, where it may be worked into the soil before seeding. Broadcasting operations may be manual, mechanical or aerial. Manual broadcasting is usually done in small nurseries or in localised areas in larger nurseries to equalise growth. In plantations, manual fertiliser application is done where hidden logs, stumps, uneven terrain and other obstacles preclude the use of machines (Evans, 1999).

Mechanical application reduces manual labour input and monetary expenses moreso if the area to be fertilized is large. The efficiency and economics of fertilisation will depend on transportation and distribution costs. Fertiliser can be applied in drills or bands between seedling rows. The ideal location of the bands will vary with the species but avoid direct contact between the fertilisers and seeds. Blowers designed mainly for tree crops are used to spread large quantities of powdered fertilisers; however, blowers unevenly distribute the fertilisers. Usually, areas nearer the blower tend to get more fertilizers, and the distant areas less, with powdered forms, and the reverse with the granules. For nitrogen fertiliser this over-concentration of fertiliser may cause root injury and adversely affect tree growth (Nwoboshi, 2000).

Aeroplanes or helicopters may be employed in broadcasting fertilizer especially in rugged topography, soft ground or areas of excessive wetness and in very dense stands where surface machinery cannot be used. The efficiency of thus method depends on: proximity of landing strip to the field to be treated, adequate facilities for loading the aircraft promptly; availability of an experienced pilot, and suitability of climatic conditions, particularly wind. The pilot's ability at maintaining parallel and equidistant flight lines may determine the uniformity of fertiliser distribution The use of blowers on aircraft may be wasteful, resulting in uneven fertilizer distribution and in fertiliser burning plants where the application is too high (Evans, 1999).

Placement methods entail applying and concentrating the fertilisers into the soil, where the plants can most readily use them to minimise fixation of the nutrients. Phosphates and potash for example, move down very slowly in many soils and may remain near the surface roots if broadcast on the soil surface, out of the reach of plant roots. Such fertilisers can be placed deeper in the soil where they are better in contact with the root system of the plants. This may involve banding or drilling the fertiliser to the sides of plant rows and placing in planting holes or around the planted trees (Nwoboshi, 1982).

Individual placement by hand ensures maximum efficiency for small or medium application rates, minimum fixation of P and K and less feeding of weeds as in broadcasting. Soluble or liquid fertilisers can be distributed in irrigation water in forest nurseries using accurate metering of solutions into measured water flows, or placing bags of fertilisers or loose powder in the streams and allowing them to gradually dissolve. The disadvantage is that acid materials and ammonium sulphate solutions also react with concrete and metal structures. Irrigation fertiliser application can also be wasteful in dry climates where water contains high soluble salts and evapo-transpiration is very high (Nwoboshi, 2000). These may lead to salt accumulation in the root zone and burning injury to the roots. Nitrogen spraying is used particularly for fruit trees and other deep-rooted tree crops where surface applied fertilisers may be of little or no use to the plants. Spraying of fruit trees has yielded positive results.

INORGANIC FERTILISER TREATMENT IN PLANTATIONS

Economic and environmental considerations underlie the selection of the appropriate fertiliser material required to produce the best nutritive condition for growing the desired tree crop. Most suitable fertiliser materials for use in forestry for instance, considerably influence the chemical and physical properties of the soil through alterations of the soil acidity and salt concentrations (Evans, 1999). The saturated solutions diffusing from dissolving fertiliser granules or bands may have acidity levels ranging from very acidic to slightly alkaline. Such saturated solutions will, temporarily alter the surrounding soils, thereby altering their chemical properties. Generally, an appropriate fertilizer the future use must have a basic or, neutral effect on soil acidity. Fertiliser application must not increase leaching of different substances from the site; rather, it should give an opposite effect (Nwoboshi, 2000).

Existing nitrogen fertilisers come either in from of solids or liquids. The solid fertilisers include: (i) the highly soluble-in-water and (ii) the slowly soluble or insoluble-in-water compounds. Widely produced compounds include the anhydrous ammonia and ammonium nitrate (Nwoboshi, 1982).

The slow release nitrogen fertilisers essentially include: (a) the organic and inorganic compounds of low water solubility and (b) the conventional soluble nitrogen fertilisers coated with insoluble or slowly soluble materials. The organic forms include urea, formaldehyde and isobutylidene, which are condensation products from urea. To adapt release patterns to some desired ends, uncoated, highly coated and heavily coated granules could be blended before application. China and the USA consume 18.7 and 9.2 metric tons of nitrogen-based fertiliser and are ranked as the world's major users of nitrogen-based compounds (FAO, 2007). The slow release fertilisers are theoretically believed to have the advantage of better utilisation by the crop as release rate is deemed to be more consistent with the rate of uptake by the plant. They also have less chance of causing mortality due to their low concentration and minimisation of losses due to leaching, volatilisation and immobilization (Evans, 1999).

Liquid nitrogen fertilisers apparently possess the potential for correcting the inefficiencies of soil application. Tree seedlings are observed to rapidly absorb nitrogen applied to the foliage in the form of dilute solutions of fertilisers. Common phosphoric fertiliser materials include: phosphoric acid and super acid grades which contain 55 percent and 99 percent of P_20_5 and are all 100 percent soluble in water (Nwoboshi, 2000). Super phosphates occur as ordinary, triple and high-anal (super acid). These have 20, 45 and 54 per cent P_20_5 and are 85%, 87% and 90% soluble in water respectively. Dicalcium phosphates include those obtained from HCl – Process and calcium metaphosphate which are sparingly soluble in water.

The choice of a phosphorus fertiliser to apply is based essentially between the water-soluble and the water- insoluble sources. When used on heavily leached soils of very low phosphorus retention capacity and very high phosphorus retention capacity soils, water-insoluble phosphorus sources such as rock phosphate show superiority over water-soluble sources such as the ordinary and triple super phosphates, particularly in duration of response (Evans, 1999). Conversely, on forest soils of moderate acidity and phosphorus-retention capacity, water-soluble phosphate sources are usually of equal or superior effectiveness on water-insoluble sources. In general, on very acid, freely drained sandy soils, where excessive leaching losses are expected, rock phosphate with high reactivity should be applied to in a coarsely ground form. For nursery soils, ordinary and triple super phosphate should be the principal phosphorus source for quick response (Nwoboshi, 1982).

Each of K, Ca, Mg and S can be supplieid individually..For example K can be supplied as KCL, Mg as MgO, Ca as CaO and S as powder. As forest plantation practices are intensified, deficiencies become more common. It may be pertinent to consider the advantages of using the other sources like K_2SO_4, KNO_3 and $MgSO_4$. To treat deficiencies of these elements on acid sandy soils subject to leaching, slowly soluble or slow-release fertiliser materials have an advantage over the above conventional sources. Potassium calcium pyrophosphate for example, shows some promise as a slow-release K source in comparison with the water-soluble materials like KCL.In case of combined S and P deficiency, the use of ordinary super phosphate in preference to concentrated super phosphate or Di-ammonium phosphate may be a suitable corrective measure (Evans, 1999).

Micronutrients can be applied as borax, copper, ferrous and magnesium sulphates, zinc chloride and sodium molybdate. These inorganic salts can become insoluble in the soil, rendering them no longer available to the plants. Chelating agents used alone or in liquid or fertiliser mixtures can overcome these problems. Alternatively, solid or liquid micronutrients may be mixed with macronutrients. Boronated super phosphate has been successfully used to treat boron and phosphorus deficiencies in parts of Australia and Nigeria (Ojo and Jackson, 1973).

The Costs of fertilisers may determine what fertilisers to apply to the forest since the concentration of the element in the fertiliser in relation to the price facilitates or prevents the application of the fertiliser. Forest nurseries make considerable demands on soil nutrients. Nwoboshi (1980) demonstrated that repeated cropping of Sapoba soils in Nigeria without adding fertilisers or manure lead to soil degradation. Fertiliser applied at the planting or the establishment phase can correct existing nutrient deficiencies in the site to minimise planting shock to the seedlings, by making nutrients liberally available to hasten crown closure. This reduces the cost of weeding. If extensively browsed species are fertilized at planting, this minimises the period the young plant is subjected to mortality or browsing damage. At this stage, the foliage forms a considerable portion of total stand biomass, increasing annually and requiring large amounts of nutrients (Nwoboshi, 2000).

In timber production, the pole stage is attained after canopy closure, when new foliage formation on the tree crowns is offset by litter fall from shaded or dead older foliage in the lowest parts of the crown. This re-establishes the nutrient cycle, decreasing the demand on soil nutrient capital and growth response to fertiliser application. (Nwoboshi, 1985).

In older crops fertiliser may be applied where the value of the trees economic component increase with age of the stand, or where such growth increases can be harvested at intermediate or final cutting. Greater financial returns can be obtained from fertilisation of older stands as this reduces the length of time that the cost of fertilisation is carried before harvest. For non-soluble elements like P, the season of application is not critical for its effectiveness if there is enough water to ensure the presence of soil solution. Highly soluble and mobile elements like N, respond poorly to the application of urea or ammonium nitrate, where intensive leaching conditions occur. Ideally, soluble N-fertilisers should be applied during periods of high root activity, moist litter and soil conditions with a high probability of moderate rainfall a few days after application (Nwoboshi, 2000).

The quantity of fertiliser required for application in plantations varies and depends on the species of trees planted, the stage of tree development, the type and chemistry of the fertiliser in the soil. Elements like P can be fixed in the soil, and large doses may be applied to accommodate the fixation. Beyond certain concentrations, excess nutrients are wasteful, uneconomic, and may even be detrimental to the growth of the trees (Evans, 1999). Excess K relative Ca and Mg may cause Ca and Mg deficiencies, while over-liming can cause micronutrient deficiencies and limit plant growth. Some elements in excess fertilizer salts can inhibit plant absorption from the soil, causing osmotic desiccation or death of root tissues.

RESPONSES OF FOREST PLANTATIONS TO APPLIED INORGANIC FERTILISERS

When fertilisers are correctly applied, they can be a justified means of increasing the productivity of trees crops. Improper application or selection of material can adversely affects non-target organisms. Some of the potential benefits in applying fertilisers to plantations as well as adverse of using fertilisers in forest crop production systems considered below .Fertilisers applied to forest plantations increase and maintain their productivity . Fertiliser use improves seed germination, growth and development, resulting in production of seedlings of plantable size .Tropical vines in Malawi and Nigeria grow faster in fertilized potting mixtures (Nwoboshi, 1973).

Fertilisation at planting efficiently increases land productivity in forestry giving the highest economic returns to any silvicultural operation (Herbert, 1986). In Hawaii, *Eucalyptus* *saligna* increased first year height growth by 127 to 500 % (Walters, 1982). Fertilisation of older crops approaching rotation age also gives highly profitable growth increments. The fertilisation of coconut (*Cocus nucifera*) improves vegetative growth, promotes early bearing and leads to high yields. With intergrated pest and disease control, yield increases of 30 per cent can be expected in Nigeria as a result of fertiliser application on soils physically suitable for cacao. Fertiliser application increases yields of forest crops and combines fast growth trees with the best possible quality, fruit, fodder and tree vegetables. The application of K and Mg to banana remarkably improves yield, and the taste of the fruit.

ORGANIC FERTILISERS:

Naturally occurring organic fertilisers include: manure, slurry, worm castings, peat, seaweed and guano. Green manure crops are also grown to add nutrients to the soil. Naturally occurring minerals such as mine rock phosphate, sulphate of potash and limestone are also considered as organic fertilisers (Wikipedia, 2007). Manufactured organic fertilisers include; compost, blood meal, seaweed extracts, natural enzyme-digested proteins, fish meal and feather meal. Decomposing crop residue from prior years is another source of fertility. Forest plantations usually span over a large area of land. In developing countries, organic fertilizer use in forest plantation is minimal, owing to its cost of acquisition and distribution, but it has value in forest nurseries with serious physico-chemical defects.

Inorganic fertilisers are generally cheaper and more efficient than organic fertilisers as source of plant nutrients, but organic amendments may become increasingly beneficial or even essential in maintaining derivable soil properties and a favourable root environment on the infertile soils often left for tree crop production. Trends towards more intensive silviculture involving drastic site preparation coupled with greater utilisation of the harvested material will reduce the amount of organic residues returned and spread their decay to such an extent that organic amendments will become necessary for the maintenance of soil fertility.

PROSPECTS OF MITIGATING PROBLEMS OF FERTILIZER USE

Bio-fertilizers are the most advanced biotechnology necessary to support the development of organic agriculture, sustainable agriculture, green agriculture, and non-pollution agriculture (www.biofertilizer.com).

Bio-fertilizer application is a sustainable approach and employs the resources of both science and nature to allow better results. Peat moss, fungi, earthworms, *Rhizobuim, Azotobacter* and *Azospirullium* have been recognized as age long bio-organisms that enrich the soil to produce safe nutritious and abundant crops (Spore, 1991, Monzote, 2006; Bio-fertilizer.com)

Bio-fertilizers contain a wide range of naturally chelated plant nutrients and trace elements, carbohydrates, amino-acids and other growth-promoting substances. The nutrient reservoir in organic matter can be made easily available for plant uptake in the following ways:

1. **kelp** acts as soil conditioner by stimulating microbial activity in the soil, sphagnum plant moss is recognized as a renewable biomass resource and is considered best overall performer as a soil amendment and substrate; it is homogenous, easy to handle and has shown the best growth results (Bio-fertilizer .com)
2. **Vermicompost** is a solution produced from organic fertilizer using kitchen wastes (Wietheger , 2005). The organic material can be converted using Earthworm species such as brandling worms (*Eisenia Foetida*) or Redworms (*Lumbricus rubellus*) . In addition to worms the vermicompost contains organisms such as insect, molds, and bacteria, which also play a role in the composting process. (Wikipedia.com). *Azotobacter virielandiis*, *Azotobacter chroococcum* cyanobacteria (blue- green algae) and *Clostridium* are free- living non-symbiotic bacteria that carry out nitrogen fixation and are important organisms in fixing atmospheric nitrogen, a key to soil nutrient restoration. (Spore, 1991; Monzote, 2006; Prasad, 2009). In addition, *Azotobacter* also fixes thiamin, ribofarin, nicotin, indole acitic acid and giberralin which are necessary for regulating growth and protecting the crop against pathogenic attacks.

***Advantages of organic fertilisers*:**
The density of nutrients in organic materials is modest, however, organic growers typically produce some or all of their fertilizer on site, thus lowering the operating cost considerably. Also, organic fertilisers are effective in promoting growth. N-supplying organic fertilisers contain insoluble N and are slow-release fertilisers. Their effectiveness can be greater than conventional N-fertilisers (Wikipedia, 2007). Inorganic fertilisers are useful in boosting plantation forestry, however, considering their serious limitations, the role of humus and other organic components of the soil play many other important roles as follows: (a) Improving the soil structure (b) Slower, nutrient release at a more consistent rate, to avoid a boom-and bust pattern (c) Retention of soil moisture, decreasing the stress due to temporary moisture stress (d) Mobilising existing soil nutrients, to achieve good growth with lower nutrient densities (e) Prevents"burning" plants with concentrated chemicals from over-supply of some nutrients (f) Organic fertilisers use forestalls the progressive decline of real or perceived "soil health", apparent in loss of structure, reduced ability to absorb precipitation, lightening of soil colour (g)The rising cost and resulting lack of independence associated with inorganic fertilisers is minimised.
(h) It is unnecessary to reapply organic fertilisers regularly to maintain soil fertility.

Disadvantages of organic fertilisers
(a) The composition of organic fertilisers varies, limiting accurate application of nutrients in matching plant production with ease (b) Improperly processed organic fertilisers derived from animal faeces or plant/animal sources may contain pathogens harmful to humans and plants. (c) They are a dilute source of nutrients compared to inorganic fertilisers; large amounts of organic fertilisers must be for profitable yields.

PROBLEMS/NON-TARGET EFFECTS OF FERTILISER APPLICATION
Fertilisation with ammonium nitrate and potassium choride reduces soil microbial activity (Nwoboshi, 2000). Contrastingly, fertilisation may have a lasting, mutually beneficial effect on soil micro-flora and fauna and observed toxic effects of some fertiliser components are only short-lived. Fertilisation affects nitrifying bacteria with the potential for nutrient leaching, ground water pollution and loss of autochthonous soil cations. Nitrification followed by de-nitrification of fertilisers may lead to global increase in nitrous oxide, and contributes to the depletion of the ozone layer in the stratosphere (Nwoboshi, 2000). Fertilisation with urea causes increases in pH and enormous increase in soil ammonium ions concentration. Mycorrhizas are most active in soils of low fertility and low pH. Fertilisation depresses these fungi species and alters their distribution in the soil. The impact varies with the type of fertiliser applied. However, P fertilisers stimulate mycrohizal growth.

Fertiliser increases disease resistance if it improves true nutrient status but will decrease if it creates nutrient imbalances. The abundant supply of nutrients may cause particular tree species to become susceptible to a particular insect attack or disease. Fertilisation can be used in certain conditions as a tool for controlling insects and the incidence of diseases. Excessive N-fertilisation can lead to pest problems by increasing birth rate, longevity and overall fitness of certain pests. (John , Almassan and Pacia, 2005).

Fertiliser pollution can affect health (animals and man) and eutrophication. Nitrates originatng from N-fertilisers contribute to both problems, while P fertiliser nutrients applied reach and influence the quality of stream or pond water through: leaching of solutes or sediments in water subsurface flow, direct application to the stream, in run-off and as incorporated organic and inorganic materials eroded or blown into streams.

Over-fertilisation is associated with the use of artificial fertilisers, because of the massive quantities applied and the destructive nature of chemical fertilisers on soil nutrient-holding structures. The high solubility of chemical fertilisers also exacerbates their tendency to degrade ecosystems (Wikipedia, 2007). The concentration of up to100 mg/kg of cadmium in phosphate minerals from some geographical locations increases soil contamination (Taylor, 1997). Uranium is another contaminant often found in phosphate fertilisers.

Globally, fertiliser use emits significant quantities of green house gases into the atmosphere through: (a) animal manures and area, which release methane, nitrous oxide, ammonia and carbon dioxide in varying quantities, depending on their form and management and (b) fertilisers that use nitric acid or ammonium bicarbonate, the production and application of which results in emissions of nitrogen oxides, nitrous oxide, ammonicim and carbon dioxide into the atmosphere (F.A.O. 2007).

CONCLUSION

Fertilisation may have a lasting, mutually beneficial effect on soil micro-flora and fauna and observed toxic effects of some fertiliser components are only short-lived. Fertilisation however negatively affects nitrifying bacteria with the potential for nutrient leaching, ground water pollution and loss of autochthonous soil cations. Nitrification followed by de-nitrification of fertilisers may lead to global increase in nitrous oxide, and contributes to the depletion of the ozone layer in the stratosphere (Nwoboshi, 2000). Fertilisation with urea causes increases in pH and enormous increase in soil ammonium ions concentration. Effective use of fertilisers in forestry must, be based on sound scientific and economic considerations required to answer questions like: what fertiliser carriers to use, when, how much, how often to apply them and by what method, what fertiliser treatments have the most favourable cost-benefit potential for the specific forest stand and site condition. Generally, an appropriate fertilizer the future use must have a basic or, neutral effect on soil acidity. Fertiliser application must not increase leaching of different substances from the site; rather, it should give an opposite effect.

RECOMMENDATIONS

- Judicious management of soil organic matter and nutrients, particularly N and P, enhances rapid restoration of ground cover between rotations and can be
- keystones of sustained productivities in a wide range of forests.
- Reduction of nitrogen removals by debarking tress and preparing stumps in-situ to leave behind the nutrient-rich barks, foliage and leaves.
- Breeding for components that influence uptake and use of nutrients by trees
- N-fixing trees species like *Acrocarpus, Albisia, Acacia, Leucaena, Prosopis, Parkinsonia, Mimosa*, *Erythrina, Glyricidia, and Sesbonia* could be inter-planted with more valuable tropical timber species
- Use of sewage effluents, municipal garbage composts and industrial effluents which have considerable potential as nutrient sources

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