1 INTRODUCTION

Southeast Asia's agriculture is at a crossroads. It is reported that about 21% (~91 Mha) of the land of the region is used for agriculture, 36 % (~33 Mha) of which is classified as ´lowland´. Half of the lowland agriculture is occupied by irrigated rice system that cannot be increased easily. Further, large areas of land under rice cultivation are also converted to industrial use and housing each year. The greatest potential for future increases in agriculture production in the region lies only in the remaining 64 % (~58 Mha) of agricultural land classified as ´upland´ or ´rainfed land´ (Dierolf et al., 2001).

With the increasing population and the fact that additional suitable land for intensive lowland agriculture is no longer available, forest encroachment for agricultural land utilization remain unabated. Increasingly, forests lands are being cleared and cultivated for continuous food production, especially those areas that are accessible to farming communities. Farmers already occupying land adjacent to and within the forest zones continue to move and expand further into the forest for cultivation. Due to lack or inaccessibility of primary forest, people now clear secondary forest at different stages of succession.

Among the cereal crops worldwide, maize ranks third economically, after rice and wheat. In Southeast Asia, maize is the second most important cereal as a staple food and as a major component of animal feeds. As the demand for maize in the region is rapidly outpacing the supply, farmers are growing more maize in the upland and marginal lands (CIMMYT, 1999).

In tropical upland soils such as in Southeast Asia, especially on soils that are generally acidic and lose fertility within a relatively short period, the cultivation for agricultural food crops using low-level inputs has been shown to collapse because of weed infestation (Sanchez et al., 1987; von Uexküll, 1995). A common phenomenon is the invasion of *Imperata cylindrica*, the most pandemic weed in tropical areas. It is reported that the invasion of *Imperata* in the uplands is a huge land degradation problem already affecting millions of hectares (Giller, 2003).

The expansion of *Imperata* areas has been attributed primarily to shifting cultivation practice, and as a consequence of continuous cultivation with annual crops but without fertilizer inputs (e.g., a cropping pattern based on maize/upland rice, cassava or horticulture plantation crops) and no permanent vegetation cover (Eussen and Wirjaharja, 1973). When forest areas are cleared for agricultural crop production and without the permanent vegetative cover, *Imperata* seeds find ideal condition to germinate. With the slash-and-burn method of cultivating the infested fields and without fertilizer inputs, the farmers may only have one or two harvests (e.g. maize or upland rice) before *Imperata* completely covers the land (van Noordwijk et al., 1997).

Once *Imperata* infested the field, it strongly competes with crops leading to declining yield. When crop production is low, the farmer has little incentive to weed infested fields. Thus, *Imperata* becomes firmly established. Also, it is indicated that unless high rates of fertilizer are applied, the continuous cultivation of these areas prone to *Imperata* for annual crops over four to five years results in soil degradation (Zaini and Lamid, 1993; Santoso et al., 1994; van Noordwijk et al., 1997).

In mid 1990s, 4 % (~35 Mha) of the total land area in Southeast Asia were already *Imperata* grasslands (Garrity et al., 1997). Indonesia is the country with the largest land area (~8.5 Mha) covered by *Imperata* (Soekardi et al., 1993). *Imperata cylindrica* is considered one of the ten worst weeds in the world (Holm et al., 1977). It is a pernicious perennial grass, native to Southeast Asia (MacDonald, 2004), and is widely spreading in tropical and sub-topical regions (Garrity et al., 1997), especially in areas under slash-and burn agriculture (Chikoye et al., 2000).

Imperata infestation is not restricted to poor soils since it occupies both fertile (e.g. Inceptisols and Andisols) and infertile soils (e.g. Ultisols and Oxisols) (Moeljadi and Soepraptohardjo, 1975; Soerianega, 1980; Garrity et al., 1997). Rather, soils with declining fertility as a result of agricultural management practices where crop production is based on the natural fertility of the soil are dominated by *Imperata cylindrica* (Moeljadi and Soepraptohardjo, 1975; Soerianega, 1980; Menz et al., 1998).

Imperata invasion poses major difficulties to restore the land for crop production, since the weed is well adapted to poor soil, drought conditions, and frequent fire regimes (MacDonald, 2004). The process is exacerbated because *Imperata* competes most effectively for nutrients and water, particularly in soils at lower fertility levels (van Noordwijck et al., 1997). It rapidly regenerates after burning (Wibowo et al., 1997) from its underground rhizomes, which is the main mechanism for its survival and spread (Chikoye et al., 2005). However, it is susceptible to shading (Macdicken et al., 1997; Terry et al., 1997).

Research on the biology and the control of *Imperata* has advanced to a point that the weed need not be a problem provided resources are available for its management (Terry et al., 1997). As summarized by Menz et al. (1998), *Imperata* control can be by physical (manual, mechanical or animal powered), chemical (herbicide use), cultural (intercropping with cover crops) or ecological (shading by competing plants), and/or the combination of the control methods (e.g. physical, chemical and ecological/cultural). Integrated approaches that combine a variety of options are always emphasized, since there is no single method that can control *Imperata* in a sustainable manner (Menz et al., 1998; MacDonald, 2004; Chikoye, 2005).

In the past, studies on *Imperata* have focused on the plant as a weed, and the prospective solutions have often been viewed as a weed control problem. Substantial investigations have been made and solutions recommended to control and manage *Imperata*. However, much of the attention has been given to existing *Imperata* grasslands (from reclamation and rehabilitation to intensified use), while inadequate attention has been given to factors involved in the evolution of *Imperata* grasslands (Garrity, 1997). The prevention of *Imperata* invasion in upland cultivated fields (from recently cleared primary or secondary forests) with agricultural annual crops remains poorly studied. So, the question posed by van Noordwijk et al. (1997) remains open and unanswered, on whether the initial degradation into *Imperata* grasslands can be slowed down or avoided when the forest is first opened, either by the development of sustainable food-crop based production systems alone, or food crops in association with tree crops production

It is generally accepted that sustained crop production depends on good soil fertility management. The spread of *Imperata* is often linked to the loss of soil fertility. The maintenance of an adequate soil nutrient status is considered one of the keys for preventing *Imperata* encroachment and stabilizing crop productivity. Also, it is indicated that *Imperata* is not a serious problem in intensively managed agricultural lands where repeated tillage or herbicide applications are practiced. But, there is still a need to integrate proven *Imperata* control and crop management strategies into the farming system so they are acceptable to the farmers and adapted to specific site conditions.

In this study, it is hypothesized that appropriate field cultivation practices could suppress *Imperata* weed infestation, such as with minimum tillage in combination with cultural control management such as fertilizer application and relay cropping with leguminous cover crops when the infestation is still below a critical level. Above that critical level, radical methods are required, which are the combinations of intensive land preparation by manual/physical or chemical control strategies with cover cropping or planting trees/shrubs to shade-out the *Imperata*. But, the effectiveness of any control strategies is likely to vary by soil types, cropping system and the level of *Imperata* infestation. To date, little is known on the site and system specificity of the combinations of *Imperata* control strategies.

Therefore, the aim of this study is to investigate the effectiveness of such combinations as land preparation and crop management practices. To know whether the degradation into *Imperata* grasslands can be slowed down or avoided in forest areas, which are recently cleared and utilized for agriculture food production. Likewise, whether maize-based cultivation systems at different levels of *Imperata* infestation can be reclaimed or protected from turning into *Imperata* grasslands.

Specifically, the study aims:

1) To investigate the feasibility of selected land preparation practices in controlling *Imperata* in fields with different levels of *Imperata* infestation and soil fertility conditions;
2) To investigate the feasibility of selected cropping management options to enhance soil fertility and at the same time control/suppress *Imperata* and weeds other than *Imperata* in cultivated fields;
3) To determine the threshold levels for the effectiveness of *Imperata* control strategies as a function of degree of *Imperata* infestation and soil fertility status and;
4) To evaluate the combinations of land and crop management strategies that enhance soil fertility, control/suppress *Imperata* infestation and increase the productivity of cultivated fields.

The research focus on the rainforests margins in Central Sulawesi, Indonesia, utilized for agrocrop production, and practically prone to *Imperata* invasions.

2 LITERATURE REVIEW

This chapter reviews the theoretical perspectives of various authors regarding the following topics that are directly related to this research.

2.1 Forest land-use change in the tropics

Worldwide, forests cover about 30% of the total land area. It is reported that total forest areas as of 2005 were already less than 4 billion hectares and continue to decrease due to deforestation. Agricultural expansion is the major contributing factor for deforestation. About 13 Mha^{-1} of forests areas were mainly converted to agricultural land (FAO, 2005).

Forests cannot be seen as stand alone systems when they are accessible to the surrounding communities. Generally, the forest is another source of food and income – forest and other non-forest products (NFPs). To farming communities, a natural forest is regarded as a resource with open access for utilization with potential areas for agricultural production. Farming activities exist around and within the forest, frequently in the forest margins. The shifting cultivation together with the ´slash and burn´ practiced by the farmers is often blamed for deforestation and its eventual degradation.

The unsustainable land management where food production is left to the natural fertility of the soil is a common forest farming practice especially in tropical countries. When the fallow periods for fertility restoration are shortened due to increasing land pressure, it resulted to land-use problems such as soil fertility depletion and weed invasion (Hartemink and Bourke, 2000). Driven by diverse socio-economic and ecological factors, forest conversion is continuing and landscapes are changing.

2.1.1 Vegetation change: forests – agriculture – grasslands

One of the clearest examples of the vegetation change (Potter, 1997) is the replacement of the forest tree cover with agro-crops, but eventually taken over by an invasive grassy weeds. The process of change starts when the trees are cut and used for timber and the remaining vegetation is cleared for agricultural purposes (primarily for agro-cropping systems). However, due to inappropriate land management and unsustainable cultivation practices, soil fertility declines to the point where the area becomes infested with persistent weeds.

Shifting cultivation has become the most practical way for farmers to escape weed problems and declining soil fertility after cropping periods. When crop production is very low and continuous cultivation eventually resulted to further decline or crop failure, the patch of cultivated land is either left fallow or totally abandoned. When crop field is unused, persistent weeds completely invade, and the fields often turn into grassland. Most especially, when the farmers are not able to cope with the persistent weeds, and continued cultivation no longer provides sufficient economic returns (Nye and Greenland, 1960; Van Noordwijk et al., 1997; Chikoye, 2005). Such changes in the vegetative cover lead to economic drawbacks and ecological changes (Eussen and Wirjahardja, 1973; Soerianegara, 1980; Van Noordwijk et al., 1997). This is particularly true after forest or long fallow (bush) clearance, followed by a cropping cycle, a duration that kills most of the tree stumps and thus slows down regeneration into bush and forest (Garrity et al., 1997; Santoso et al., 1997; Snelder, 2001).

2.1.2 Declining soil fertility and weed invasion

With the new land-use and the ecological disturbance through agricultural activities, the closed nutrient cycle of the forest becomes open to nutrient flows, with an increasing imbalance between nutrient uptake and return to the soil (Hairiah et al., 2000). As Bationo and Vlek (1997) indicated, in many cropping systems little or no agricultural residues are returned to the soil. The nutrient cycle is interrupted by the export of nutrients out of the system during harvest and burning. The removal of harvested products and movement of fertile topsoil out of the field through erosion and leaching increases the nutrient losses. This is mostly observed in the uplands of humid tropical regions such as in Southeast Asia, where runoff/erosion and leaching has caused N, Mg, Ca, K and S deficiency (Härdter and Fairhurst, 2003).

The continuous cultivation without nutrient returns eventually resulted to nutrient depletion of initially fertile soil. The soil organic matter content declines with time while this reduction in fertility leads to a poorer structure, water holding capacity and lower biological activity, and thus in lower soil productivity and crop yield.

Overall, the soil characteristics of the area change rapidly (Schoenau and Campbell, 1996; Vlek et al., 1997; Derksen et al., 2002).

With low soil organic matter content, there is often a rapid and persisting weed growth. In time, certain species tend to predominate as they win the struggle for space. Repeated soil cultivation causes suppression of typical fallow species and favors the growth of adapted arable weed species, thus changing the vegetation composition (Nye and Greenland, 1960; Sanchez, 1976; Macdicken et al., 1997).

2.2 Agricultural food production and *Imperata* invasion

According to von Uexküll and Mutert (1995), the acid soil land areas in the tropics represent the last and largest reserve of potential agricultural land in the world. Most of these lands are classified as forests areas and provided a temporary subsistence to small farmholders practicing shifting cultivation. It can not sustain continuous agriculture with conventional low-input techniques. Once the forest cover is removed, most of these acid soils quickly lose their residual fertility and thus abandoned after only a few years of cropping.

According to the Potash and Phosphate Institute (PPI) (http//:www.ppi.org), the major soil nutrient problems of these acid upland soils are the low N, P and K status and Al toxicity. Further indicated that K and Mg are particularly deficient in soils that have been cropped for several seasons, where crop residues have been removed, and little or no K and Mg fertilizer has been applied.

Each farming system produces its typical weed population as a result of cultivation practices, local climate and soil conditions. Under tropical conditions, *Imperata cylindrica* is one of the worst weeds and is considered the most serious noxious weed in many countries of Southeast Asia (Garrity et al., 1997; Potter, 1997; MacDonald, 2004). *Imperata* invasion and low production after some years of continuous cultivation is common in Southeast Asia´s agricultural upland food production systems (van Noordwijk et al., 1997) and a serious land degradation problem that are already affecting millions of hectares (Giller, 2003).

In tropical areas like in Southeast Asia, vast tracts of land with previously productive forest cover have degraded to anthropogenic savanna after clearing for agricultural cultivation (von Uexküll and Mutert, 1995). Garrity et al. (1997) estimated that about 35 million hectares (4 % of the total land area) in the region were already covered with *Imperata* grasslands. Countries with the largest area of *Imperata* grasslands are Indonesia (8.5 million ha) and India (8.0 million ha). Countries with the largest proportion of the land covered with *Imperata* grassland are Sri Lanka (23 %), the Philippines (17 %), and Vietnam (9 %). In Laos, Thailand, Myanmar, and Bangladesh this area is about 3 to 4 %. Less affected are Malaysia (<1 %), Cambodia (1 %), and the southern part of China (2 %).

To slow down further forest encroachment in the tropics and at same time to provide badly needed land for future food production, efforts have been geared to rehabilitate deforested and degraded lands, including the *Imperata* grasslands. It is recognized that if technologies are developed and introduced that permit sustainable and profitable agriculture in the fragile and infertile acid soils of the tropics, there is still a large potential to increase the area under cultivation (von Uexküll and Mutert, 1995).

2.3 Characteristics of *Imperata*

2.3.1 Taxonomy and status

Imperata is a genus of the Poaceae, a grass family (Gabel, 1982; MacDonald, 2004), and is composed of two sub-genera, *Imperata* and *Eriopogon*. The subgenus *Imperata* has only one species, the *Imperata cylindrica* (Garrity et al., 1997). Hubbard et al. (1944) and Santiago (1980) classified *Imperata cylindrica* into five taxonomic varieties – *major, africana, europa, latifolia* and *condensate* (Tjitrosoedirdjo, 1993; Garrity et al., 1997; MacDonald, 2004). *Imperata cylindrica* var. *major* is indigenous throughout Asia and predominant in Southeast Asia, Australia, China, Japan, the Philippines, and East Africa. *Imperata cylindrica* var. *africana* is found in West Africa. *Imperata cylindrica* var. *europa* is found in the Mediterranean and Central Asia. *Imperata cylindrica* var. *latifolia* is found only in north India. Variety *condensate* is found in Chile (Hubbard et al., 1944; Santiago, 1980; Bewick et al., 1997; Shilling et al.1997; Garrity et. al., 1997; MacDonald, 2004). *Imperata cylindrica* varieties *major* and *africana* are considered most serious (Townson, 1991; Terry et al., 1997; Chikoye, 2005). Most research was conducted on these two varieties because they are the most widespread, damaging and variable (Brook, 1989; MacDonald, 2004).

The *Imperata* weed is considered to be of major significance primarily due to *Imperata cylindrica* (Gabel, 1982; MacDonald, 2004). *Imperata cylindrica* (L.) Raeuschel or Beauv (as corrected by Gabel, 1982) is ranked as the seventh most troublesome weed worldwide (Holm et al., 1977; Terry et. al., 1997; MacDonald, 2004).

2.3.2 Biological features

As described by various authors (Hubbard et al., 1944; Holm et al., 1977; Brook, 1989; Shilling et al., 1997; Terry et al., 1997; MacDonald, 2004; Chikoye, 2005), *Imperata* is a warm-season, rhizomatous, perennial C4 grass with a spreading habit and reproduces sexually from seed and vegetatively by rhizomes. It spreads and dominates in areas disturbed by human activities.

The plant is without stems and the leaves grow from the rhizomes and have stomata on both surfaces. A fibrous root system spreads from the rhizomes. The branched rhizomes form a dense mat, which is able to exclude most other vegetation. The sharp apical ends of the rhizomes may grow through the roots of other plants. Rhizome development starts between the third and fourth leaf stage, varying in number from one to four rhizomes. Early rhizome growth is plagiotropic, or vertical, with growth by the fifth leaf stage becoming horizontal and the rhizomes covered by scale leaves (cataphylls). The tips of the rhizomes grow upward (negatively orthogeotropic) between the fifth and sixth leaf stage. The rhizomes can give rise to 350 shoots in 6 weeks and can cover 4 m^2 in 11 weeks. Second generation shoots and rhizomes form simultaneously on strong plants, in which the shoots arise from the apical bud and rhizomes form from sub-apical buds. In weaker plants, the shoot forms first, while buds on the convex side form shoots much later or remain suppressed (Hubbard et al., 1944; Boonitee and Ritdhit, 1984; Eussen and Soerjani, 1975; Eussen, 1980; Ayeni, 1985; Shilling et al., 1997).

Imperata is a prolific seed producer with seedheads that are branched but compacted into a dense, white, fluffy, spike-like panicle, 10-20 cm long (Holm et al., 1977). A single plant may produce as many as 3000 seeds (Sajise, 1972), which are small and are attached to a plume of long hairs that facilitates wind dispersal to a distance of 15 miles or more (Hubbard et al., 1944) and have little or no dormancy period and can remain viable for over a year (Hubbard et al., 1944; Santiago, 1965;